California Energy Commission

CONSULTANT REPORT

Codes and Standards Enhancement – Quality Demonstration Program

Appendices A-B

California Energy Commission

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January 2019 | CEC-500-2019-005-APA-B

APPENDIX A: CASE-Quality Demonstration Program Manual

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Chapter 1
CASE-Quality Demonstration Program

The Codes and Standards Enhancement – Quality Demonstration Program (CASE-QDP or Program) supports demonstration of energy-efficient building technology in order to usefully inform California codes and standards (C&S) activities. The CASE-QDP bridges the gap between small, pilot scale technology demonstrations and broad, market transformation programs currently supported by the Energy Commission and others. Assessments conducted under this program produce complete and detailed technology reports that may be used by the Energy Commission, utilities and other stakeholders as part of their Codes and Standards Enhancement initiatives (CASE). The CASE-QDP optimizes and leverages its funding to support technology development and C&S enhancements.

The guidelines and procedures contained in this Program Manual can be used by any project team in need of information on how to conduct a robust and well-documented technology demonstration. In addition to providing this resource, the CASE-QDP directly supports identification, selection, installation and performance assessments of energy-efficient building technologies ready for current or near-term inclusion in California C&S initiatives. Projects conducted through this Program adhere to the procedures and guidelines contained in this Program Manual.

Figure 1: Research, Demonstration and Commercialization Pipeline

Program Objectives

The principal objectives of this Program are to support evaluation of emerging technology with the potential to improve the efficiency and performance of California buildings and appliances. This Program Manual describes the Program and provides methods and procedures necessary to conduct meaningful technology assessments that usefully inform C&S activities. This Program Manual serves these objectives by:

- Providing consistent methods and procedures for conducting technology demonstrations to ensure quality and useful demonstration results
- Providing standard requirements and templates for reporting outcomes that are synchronized to the needs of the codes and standards process.

The Program funds a variety of technology and design best-practice demonstrations. Each demonstration must follow a well-defined format to ensure project outcomes are well supported, well documented and useful for future C&S enhancement activities, if needed. The following sections of this chapter provide information that should be considered and a structure that should be followed for any demonstration conducted as part of the Program. In addition, this information provides a useful guide for others who wish to conduct a demonstration project that will deliver meaningful, comparative information on a technology's performance and market impacts.

General Approach

The majority of projects conducted under the Program will proceed as a retrofit or alteration of an existing space to accommodate and demonstrate a new product or practice. The general approach for this type of demonstration project, therefore, is based on in-situ measurement and verification (M&V) of the baseline conditions and systems, followed by post-retrofit evaluations of the demonstration technology. Outcomes are used to calculate resource savings and document other performance attributes.

Projects conducted as part of the Program, or in accordance with its procedures, follow a general approach beginning with identification of demonstration technologies and sites, and ending with reporting demonstration outcomes. There are six major components of a technology demonstration project, in addition to technology installation at the host site. These major Program components are detailed in Figure 2: General Approach for a CASE-Q demonstration project. Each of these components is discussed in detail in Chapter 3 and Chapter 4.

Figure 2: General Approach for a CASE-Q Demonstration Project

Program Administration

The CASE-QDP Program is funded by the Energy Commission's Public Interest Energy Research program (PIER). The CASE-QDP is managed by the California Lighting Technology Center, University of California, Davis. Partners include the Western Cooling Efficiency Center at UC Davis, Southern California Edison, ICF International and New Buildings Institute. Program funding for the 2014-2017 cycle is fully earmarked for program development and technology demonstrations. Inquiries regarding future CASE-QDP opportunities may be directed to the PIER Program Manager or authors of this document.

Chapter 2
Market and Economic Analysis

Market and economic analysis is a key element of technology demonstration projects. By understanding the market, Program participants can more effectively estimate the savings impacts of a demonstration measure. Economic analysis is often dependent on information gathered during the market assessment, and this analysis is revisited during post-retrofit project and reporting activities. The following sections describe the reasons for and types of information to consider during a market and economic assessment of potential or selected demonstration technologies. When conducted at the earliest stages of a demonstration project, these analyses can focus selection of individual technologies, host sites, or other project parameters, to ensure the most impactful outcomes.

Market Analysis

Market analysis is necessary to understand, segment and quantify the building or appliance sector served by a potential or selected demonstration technology. Market analysis is also useful to define market opportunities and assess the potential benefits of adopting particular technologies or services. This type of market information is useful for two reasons. Market information is necessary to accurately quantify the total potential energy and cost impacts of the demonstration technology. The size of the affected market will help determine if a particular technology or practice should be considered for future codes and standards enhancement measures. Technology with the potential for significant energy or other resource savings is considered a priority during C&S enhancement activities.

Market Size

Market size is an important consideration for any technology demonstration project. Energy and other resource-use estimates are often based on market size. The size of building and appliance markets can often be established from existing reports provided by government agencies, consulting firms, or utilities. Reports detailing the energy use of various technologies are available through the U.S. Department of Energy (DOE), for example. In addition to federal agencies, the California State government's various state agencies (Energy Commission, CPUC, etc.) release annual resource-use estimates of various building technologies and sectors including estimates of electricity, gas and water use. Information may include metrics like hours-of-use, use intensity, climate data, and Time Dependent Valuation (TDV) of resources. Once applicable reports are obtained, the market resource use, often disaggregated by various sectors, can be quantified. The more information that can be reviewed about the affected market segments, the better the demonstration report.

The market for compact fluorescent lamps in commercial applications has been estimated by a number of different organizations. U.S. DOE published a report titled Lighting Market Characterization. This report identifies the type, energy consumption, and quantity of light sources installed in the U.S. This data can be further segmented into various lighting applications that fall within the commercial sector, such as: office, retail, and education.

Data Segmentation

Market data must often be segmented into subsets specific to the particular industry or end-use application served by the demonstration technology. This can be as simple as identifying which products are available in the California market, and determining their efficiency and other related characteristics. Depending on the product, the metrics of importance will vary, however, three general types of metrics apply to most technologies: service delivered (examples: light output, cooling capacity), product efficiency/efficacy (luminaire efficacy), and cost.

Approximately 16% of residential kitchens in the United States utilize incandescent reflector lamps. The majority of products are offered by large manufacturers with national distribution channels. A product survey reveals multiple brands, product lines and product options. As products are identified, they are catalogued and important characteristics noted. These lamps could be categorized by their amount of light output, source efficacy (light output / wattage of the lamp), and retail product cost[1].

Market data may also require additional discretization in order to make sure similar products are being considered and compared during the analysis phase of the demonstration project. Product discretization can be accomplished by grouping products that have similar work capacity or other performance characteristics. Once grouped, each segment is often further segmented by efficiency or efficacy. This type of analysis is necessary to ensure the market opportunity is properly characterized and the benefits of a particular technology demonstration are accurately documented as compared to other existing products, design practices, or base cases.

Historically, high intensity discharge (HID) lamps were utilized in outdoor applications because they were the most efficacious light source for producing large quantities of light. One of the most efficient HID light sources is the low pressure sodium lamp (LPS), which produces light in a very narrow spectrum of wavelengths with a yellow hue. If we did not consider quality of the LPS light, the source would appear to be a great energy-efficient alternative to incandescent

1 U.S. Department of Energy, Energy Efficiency and Renewable Energy, "2010 Lighting Market Characterization. "January 2012.

lamps. However, by understanding the amount and quality of the light produced by the LPS lamp, we are able to avoid the pitfall of comparing this product to an incandescent, which is a source used for high CRI (high color quality) applications.

Economic Analysis

Economic analysis is important throughout the CASE-QDP process. Planning activities, including calculation of expected resource and cost savings, will provide justification for demonstration funding, help determine the overall scope of activities, and assist stakeholders with preliminary indicators that could affect a technology's inclusion in related C&S efforts. Post-retrofit analysis is absolutely critical to compare estimated to actual performance, quantify the potential cost and resource impacts of the demonstrated technology; and provide evidence to support current or future C&S measures.

Life-Cycle Cost Analysis

Demonstration projects should include a life-cycle cost analysis (LCA). This type of analysis estimates the total cost of ownership for a technology or system over its useful life. Life-cycle costs include purchase costs, installation costs, operation costs, maintenance costs and disposal costs. The life-cycle cost of the demonstration system is compared to the life-cycle cost of the incumbent system in order to determine the overall value of the measure based on life-cycle attributes. This includes costs of

- Materials
- Installation
- Resource Use
- Maintenance
- Replacement
- Salvage value

Demonstration projects should include three versions of life-cycle cost analysis. An estimate of the general (non-site specific) life-cycle cost should be completed prior to or in parallel with site selection. This analysis will be based on typical, sector-specific and historical cost estimates. A second life-cycle cost analysis should be conducted after a demonstration site is selected. The second analysis will include modified assumptions based on site-specific costs and operating conditions. A third analysis should be conducted after the post-retrofit M&V process is complete, in order to update the site-specific LCA to reflect actual, in-situ performance.

Types of Life-Cycle Costs

Adoption of new technology often requires replacement of existing products. The total cost of any project requires the consideration a variety of factors over the life of the product, not just the initial cost of the new product itself. Six types of costs should be considered and included in the program LCA.

Materials

Material costs are often highly variable due to distribution cost mark-ups, volume pricing and other bargaining agreements. Material costs documented in a technology demonstration project report should be representative of the costs for the affected market sector served by the demonstration technology. Often, demonstration projects are small in scale and material costs are elevated due to lack of volume or other discounts often associated with larger-scale projects. While actual demonstration-project cost information is accurate, it is also useful to provide estimated cost information for the demonstration technology when installed in larger, full-scale new construction or renovation projects. It is important to provide the expected cost to the consumer or end-user in the target market sector.

Installation

Much like material or product costs, installation costs are highly variable and are both site and sector dependent. Installation costs can be categorized as either *contractor-installed* or *site-installed*. Installation costs often do not include material costs, building permits, or disposal fees. Site-specific installation cost dependencies may be associated with site access limitations, hours of operation, safety requirements and regional prevailing wage rates. In addition, small retrofit projects will often have a higher per-unit installation cost than larger projects. Thus, project size must be considered and included in any installation-cost documentation.

> *Lighting retrofits completed at a building with asbestos may result in additional costs associated with asbestos removal. These costs may not be representative of the chosen market segment, and therefore these costs should be separately documented, apart from the calculated cost of a typical installation.*

Demonstration projects often include novel or emerging technology with which the installation contractor or site personnel have little or no experience. In these cases, an accurate installation-cost is hard to estimate in advance, and it is often better to base the assessment on the actual project installation costs. Installation costs are often estimated based on personnel pay rates and work time estimates; however, these estimates should be reevaluated after completion of the actual demonstration project. In addition, demonstration teams should investigate if there are certified contractors with special training, skills, or experience with installation of particular products/systems to reduce contingency markups, reduce installation time, and minimize installation costs.

Any installation cost estimates or documentation should include a total project installation cost and a per-unit product installation cost, if applicable. Typical per-unit cost metrics include cost-per-product installed or cost-per-area of project. Costs for atypical installation requirements should be separated from the base installation cost and recorded.

Resource Use

Any technology demonstration project will include resource costs. Examples of resources are electricity, water and natural gas. Resource costs can often be variable and based on time-of-day, season or consumption volume. Demonstration products consume resources, and the cost of consumption must be calculated and included in project documentation. Often, resource-cost savings is the primary driver behind adoption of an emerging technology; therefore, any variance between existing/current technology resource-use and demonstration technology resource-use should be detailed and explained. For many applications and technologies, the use of the Energy Commission's Time Dependent Valuation (TDV) methodology is recommended when calculating and documented resource costs. Procedures for developing, conducting and documenting energy demand and savings from an energy conservation measure (ECM) are provided in Chapters 3-5.

Maintenance

Maintenance costs are a very important part of any technology demonstration and should be accurately quantified and documented. Proper maintenance-cost calculations are often more complex than installation and materials-cost calculations because they are based on multiple other types of costs as well as the estimated performance/life cycle of the demonstration technology. Additionally, the type of maintenance personnel, contractors or on-site staff utilized effect the overall maintenance cost.

In general, there are two kinds of maintenance - preventative and emergency. Preventative maintenance occurs at set time periods or after a certain number of usage hours. Emergency maintenance is conducted when there is a fault or failure that requires repair in order for the unit to continue operation. Some end-users pay companies to handle one or both kinds of maintenance while others utilize in-house staff. In the case of contracted maintenance, costs should be based on an itemized quote or receipt, a separately reported based on maintenance type.

In cases where on-site staff are responsible for maintenance, there are two options to determine preventative maintenance costs. The first is through estimation. Maintenance costs are composed of both a labor and a materials component. Surveying or interviewing staff can assist in determining the length of time required for a given maintenance event and the type of materials required. Once the material requirements are determined, a cost associated with the materials can generally be obtained through existing purchase orders for previous maintenance events. Alternatively, obtaining a quote from a vendor can achieve the same result.

Emergency maintenance is the most difficult maintenance type to accurately quantify. Depending on the expected life of a product and the length of time included in the cost analysis, emergency maintenance costs may not be appropriate to include. Often times, an emergency maintenance event can only result in the wholesale replacement of the product. Research and documentation on the serviceability of the demonstration product is required to determine which avenue of action makes the most economic sense.

> *When the failure of a luminaire occurs, there are two options - the replacement of the entire unit or the maintenance of its components. In the case of standard fluorescent luminaires, it is often more economical to replace the failed component - often a lamp, ballast or socket. However, in the case of some luminaires, often those that require a large amount of time to service, it may be more cost effective to replace the entire luminaire and reduce additional maintenance in the near future.*

Replacement

The lifespan of some products cannot be extended through preventative maintenance. Other products become obsolete over the course of their life and it makes more sense to replace rather than repair them. In these situations, replacement costs are similar to material and installation costs, except that additional disposal costs should be considered. Disposal costs are often depend on product composition. Products that contain hazardous or toxic material can often be more expensive to dispose of. Check with the California Environmental Protection Agency to determine if there are specific restrictions to dispose of incumbent products. If there are specific requirements, consult your local waste disposal agency to get a quote for the disposal of the product given the specific constraints described by the EPA. Otherwise, disposal should follow the same guidelines the demonstration site uses to dispose of normal waste materials.

> *Buildings built before 1979 may contain lighting ballasts that use polychlorinated biphenyls (PCB). PCB's are a toxic material that must be disposed of following the EPA's recommended guidelines. In scenarios where luminaires with PCB ballasts are currently installed, it is often most cost effective to replace the fixtures with new energy efficient lighting, as opposed to trying to retrofit the fixtures which are already outdated. Most waste management companies will provide quotes for the disposal of PCB ballasts, a disposal cost that must be included to determine full replacement cost for the existing luminaires.*

Residual Value

The residual value of a product is its remaining value at the end of its useful life. Residual value can be stated in a variety of ways. The most common methods are resale value, salvage value, or value based on scrap and disposal costs. Additionally, prorating the total initial cost of the product including its installation across the total life of the product, and estimating the residual value as the value remaining at the end of the cost-analysis period is acceptable.

Prorating example:
*An induction luminaire operates 12 hours a day, 365 days a year, has a 100,000-hour lifespan. You are conducting a 15-year LCA. After 15 years, the luminaire will have operated for 65,700 hours. The cost to purchase and install the luminaire was $300. The luminaire's residual value is based on the remaining useful life of the product. 100,000 (total life span) – 65,700 (consumed life) = 34,300 hours or 34.3%. The residual value is 0.343 * $300 = $102.90.*

Chapter 3
Assessment Methods and Tools

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) publishes a guideline for Measurement of Energy and Demand Savings (ASHRAE Guideline 14-2002), which covers most aspects of project assessment methods, measurements and tools applicable to the Program. This Program borrows heavily from that guideline for measurement and verification (M&V) activities. Where applicable, demonstration teams should reference detailed procedures contained in that document, in addition to various industry accepted standard test methods. Some additional specific methods are discussed for select types of technology demonstration projects and the referenced documents should be consulted for details. A list of referenced standards is provided in Appendix B.

Measurement Approach

There are three general ways to approach measurements for quantifying energy-use: whole building monitoring, retrofit isolation, and calibrated simulation (ASHRAE Guideline 14-2002, Section 5). CASE-QDP Assessments will most often utilize the **retrofit isolation approach** to determine the energy and demand savings as described in ASHRAE 14-2002. A whole building approach will typically be inappropriate because it does not sufficiently isolate energy use for the individual demonstration technology. Additionally, the calibrated simulation approach is essentially the retrofit isolation approach with a more complicated model. While program assessments should most often utilize the retrofit isolation approach, some studies that seek to evaluate more complex systems may borrow from either the whole building monitoring approach and or the calibrated simulation approach to fully characterize the system. More information on these approaches may found in ASHRAE 14-2002.

In the retrofit isolation approach for energy measurement, meters and data loggers are used to measure and record energy-use information only on the technology or measure under consideration. The energy-use of the technology under examination is "isolated" from the rest of the building or other connected systems. Measurements are taken before and after the installation of the demonstration technology. Savings derived from these measurements may be used to estimate the energy use of similar technologies operating under similar conditions. The process consists of the following general steps, conducted in combination with the activities to design and conduct the study (Chapter 4):

1. Select independent variables and develop a baseline model
2. Select and document baseline conditions

3. Select duration and frequency of monitoring period for baseline and post-retrofit scenarios
4. Project baseline usage to post-retrofit conditions
5. Determine savings: Projected Baseline Use – Post-Retrofit Use

Explanatory Variables and Modeling

A primary objective of any field study is to accurately determine the energy or demand savings that may be attributed to use of a new product or practice. For many studies, it will be hard to strictly control all variables that affect energy use between a baseline scenario and a post retrofit scenario. Uncontrolled or undocumented variance can often lead to skewed results that do not represent actual, sustained savings. To mitigate this risk, data should be collected on all identified variables, so that they may be properly recorded and used for any future modeling analyses. Models can be created that correlate the system energy use with changes in these influential building, environmental or other variables. Models may use basic averaging, regression or other appropriate techniques. With those models, the conditions can be applied in such a way to allow for a direct comparison of technologies across multiple demonstration sites or studies with a corresponding fair characterization of energy savings.

Independent and Dependent Explanatory Variables

Many different factors, or explanatory variables, affect the energy use of a product or system. Common examples of explanatory variables are outdoor temperature and building occupancy. Explanatory variables can be independent or tied to the conditions of other variables within the environment (dependent). Consider a study of Heating, Ventilation and Air Condition (HVAC) electricity use in a retail space. The store may only operate during the day when the weather is relatively warm. Because the store is often crowded, occupancy contributes to the heat present within the space. The temperature in the store depends on the two variables of weather and occupancy, and, in this case, is not truly independent at all. Dependence between variables will often influence the type of modeling approach that should be utilized for a particular demonstration project.

Modeling Effects of Explanatory Variables

System modeling is often used to analyze technology installations and associated energy-use under comparable conditions. There are two modeling approaches often used as part of the retrofit isolation approach: regression and simulation. Regression establishes correlations between explanatory variables and energy use. Regression methods are only appropriate for systems characterized by independent, explanatory variables. If they are not, energy use models may not be accurate. In cases where the interaction between explanatory variables is strong, as in the example from the previous section, a simulation model may be more appropriate. More information on regression and simulation models may be found in ASHRAE 14-2002.

Once a suitable model is developed, it should be tested for Net Determination Bias (NDB) to ensure it does not introduce any unnecessary error into savings calculations. A procedure for calculating the NDB of the baseline model is provided on page 19.

Conditions and Monitoring Periods

The selection of an appropriate baseline and post-retrofit monitoring period will be guided by the anticipated and actual operating conditions. A monitoring period that includes all possible conditions is preferred in order to reduce uncertainty in energy computations and reported outcomes (ASHRAE 14-2002 5.2.2.). For most HVAC technologies, 12 months of pre-retrofit data is required to properly document all modes of operation under all operating conditions.

For baseline monitoring, the period immediately preceding installation of the demonstration technology is often most appropriate because this will reduce the probability that changes in conditions between pre and post-retrofit monitoring periods will or have occurred. Similarly, for post-retrofit monitoring periods, the monitoring duration should be such that it includes all modes of operations for the demonstration technology. It is usually insufficient to set an absolute monitoring period, independent of these considerations. Some existing literature and protocols recommend this approach, but this should be avoided unless it can be sufficiently demonstrated that the selected monitoring period will appropriately characterize all modes of operation for the incumbent and demonstration technology.

Regardless of the monitoring period duration, the following items, at a minimum, should be documented for both baseline and post-retrofit conditions. Documentation of additional conditions may be appropriate. Photos of baseline and post-retrofit conditions should be collected whenever possible. Additional information is provided in Chapter 4.

- Facility operating schedules (business hours/hours of operation)
- Non-routine events affecting the operating schedule during the monitoring periods
- Building features affecting the demonstration systems (ex: size and location of windows or skylights for daylight harvesting controls projects)
- Occupancy patterns
- Number of space or building occupants
- Type of work or activity conducted at the facility and in the demonstration space
- Inventory of incumbent devices and systems related to the demonstration technology
- System set points (ex: task tuned light level, HVAC set points)

If changes occur between the development of the baseline and the completion of the demonstration's post-retrofit monitoring and verification period, the effects of those changes must be quantified and the data that has been collected must be normalized to reflect changes in the baseline. For example, if conducting a study of daylight harvesting in side-lit areas and a set of shade trees are planted halfway through the study, the data associated with the project to before and after the shade trees would not be comparable. ASHRAE provides guidelines on how to approach accounting for these changes in Guideline 14 (ASHRAE 5.2.8.3).

Data Collection, Analysis and Calculations

Depending on the type of technology under evaluation, one of several methods may be utilized for data collection. Technologies with constant use and loads (each varies by less than 5% over the year) are the simplest type, and data collected may consist of spot energy-use measurements before and after technology installation. Technologies with varying loads or use patterns require time-series data collection to characterize the true energy use. Periodic or continuous pre- and post- retrofit data collection over time is most ideal for all cases, but often not required. More information on the data collection procedures appropriate for use with the retrofit isolation approach may be found in Section 6.2 of the ASHRAE 14-2002 guidelines.

Missing or corrupted data

Monitoring data may be lost for a variety of reasons including equipment failure and corruption of digital data files. When data is lost, demonstration teams must document the loss and any procedure followed to estimate or correct the data for the lost period. There are several methods that may be utilized to estimate or rebuild the lost data set included interpolation methods. Alternatively, data for that period may be omitted. Teams must maintain a record of the raw data and a detailed description of how any lost data was replaced, if applicable. When data is missing from the post-retrofit monitoring period, it may be replaced with estimated values provided the estimations are based on other post-retrofit monitored data that spans the same mode of operation and conditions as the missing data set.

Quantifying Uncertainty

Uncertainty is a way to convey the potential for error in measurements. Uncertainty is composed of components due to sampling error, measurement equipment error, and modeling. It is important to quantify uncertainty based on these factors before a project is started to ensure the proposed methods will yield significant results. It is recommended that uncertainty be calculated in terms of a confidence interval with a maximum uncertainty level of 50% of annual reported savings at a 68% confidence (ASHRAE 14-2002 5.3).

When using the retrofit isolation approach to determine energy and demand savings, the overall uncertainty is composed of just two of the three components: modeling uncertainty and measurement uncertainty. Zero measurement uncertainty may be assumed for utility bill data and weather data reported by a government-operated weather reporting service in the United States or Canada. Additional details on computing savings uncertainty are provided in Annex B of the ASHRAE 14-2002 Guideline.

Net Determination Bias

Baseline models should not introduce unnecessary and additional error (bias) into calculations. Once a mathematical formula (model) is developed to describe the baseline, based on explanatory variable(s), the baseline data should be recalculated using the model. The recalculated data set, along with the original measured baseline data set is then used to determine the Net Determination Bias (NDB) of the model expression. The NDB should be no more than 0.0005% (ASHRAE 14-2002 5.2.10).

$$NDB = \frac{\sum_{n=1}^{n}(X_n - X'_n) * 100}{\sum_{n=1}^{n} X_n}$$

X = baseline data point

X' = recalculated baseline data point

Net Energy Savings

A demonstration's net energy savings (NES) is the difference between adjusted (actual baseline recalculated with post-retrofit conditions) baseline energy use (BEU) and post-retrofit energy use. As discussed above, to make an accurate comparison between systems, they need to be compared under similar operating conditions. To do this, BEU is recalculated using an appropriate model (refer to page 16 for information on developing baseline models) that is adjusted for the operating conditions present in the post-retrofit period.

$$NES = BEUa - PEU$$

NES = Net energy use

BEUa = Baseline energy use (adjusted)

PEU = Post-retrofit energy use

Energy use may be dependent on a number of independent variables such as outdoor air temperature or building occupancy. Baseline data must be projected into the post-retrofit period to adjust the data for post-retrofit conditions. This is accomplished by using the baseline model. For example, a demonstration team collects two streams of baseline data for an upcoming lighting retrofit project: lighting electricity use (BEU) and building occupancy (BO_{pre}). Using these two datasets and applying a suitable mathematical modeling technique, it is determined that the data is best represented by a polynomial function,

$$BEU = f(BO_{pre})$$

Following post-retrofit data collection of lighting energy use (PEU) and building occupancy (BO_{post}), the team adjusts the baseline data to account for post-retrofit occupancy conditions. The adjusted baseline energy use can then be directly compared to the post-retrofit energy use to determine savings.

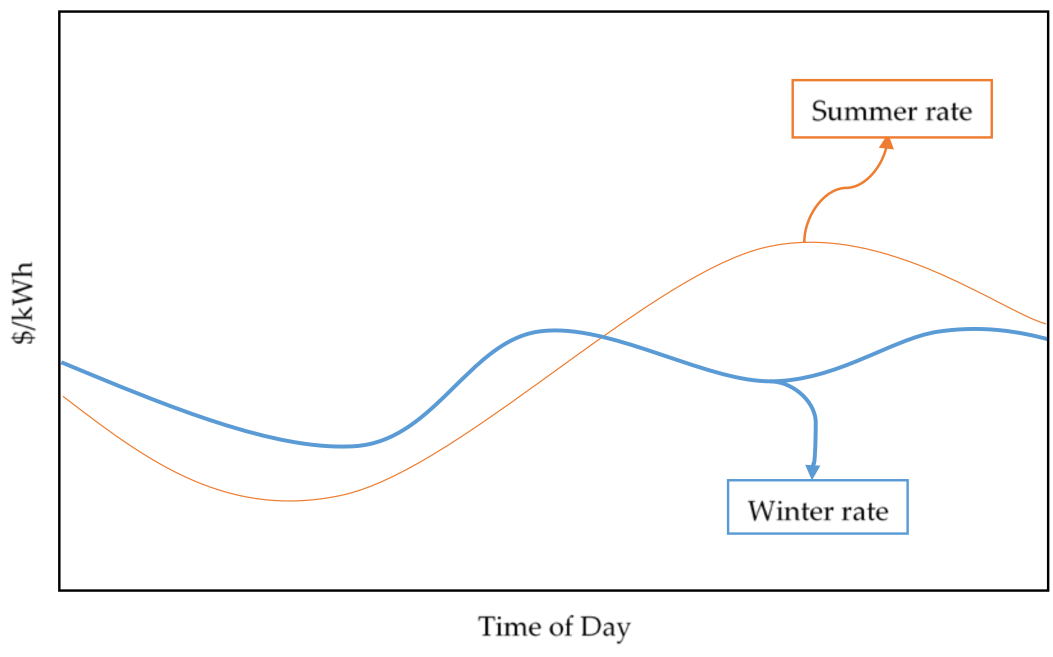
$$BEUa = f(BO_{post})$$

$$NES = BEUa - PEU$$

Energy Valuation and Cost Savings

An additional factor to consider beyond energy use is energy cost. Time dependent valuation (TDV) of energy allows energy cost analysis to factor in the dynamic cost of natural gas, electricity and methane. The cost of these resources can vary depending on a number of variables including but not limited to: time of day, temperature, season, supply and demand, location resource generation conditions, cost of emissions, global events. The use of these methods should be utilized to determine the energy costs associated with Program demonstrations.

Figure 3: Daily and Seasonal Electricity Price Fluctuations (Example Only)



The TDV of resources requires a firm understanding of the demonstration's M&V data. Energy Cost Savings (ECS) is equal to the sum of the products of the hourly NES, TDV factor for that hour of data, and the energy cost summed over the entirety of the data set.

$$ECS = \sum EnergyCost * F_{TDV} * NES_H$$

F_{TDV} = Time Dependent Valuation Factor
EnergyCost = Cost of Energy (ex: $/kWh)
NES_H = Hourly Net Energy Savings

Energy and cost savings calculations should be provided with its corresponding uncertainty and confidence interval as discussed previously.

Metering Tools and Equipment

Many factors should be considered when selecting metering tools and equipment for use in a demonstration project. There are many options for measuring common physical properties like temperature, pressure, fluid flow and power; each with its own set of benefits and limitations. It is beyond the scope of the Program to prescribe the use of the any one particular type of metering device, sensor, or data collection system; however, a minimum level of precision and accuracy should be maintained. These minimum requirements are provided below along with a brief overview of the types of metering tools and equipment often used in the measurement of demand and energy performance of building systems. Regardless of the particular monitoring and verification equipment utilized, the following information must be recorded for devices and their installation locations:

- Device name and short description
- Measurement type
- Measurement point name(s)
- Installation method
- Installation location
- Expected range of values
- Calibration requirements
- Date of last calibration

Minimum Requirements for Measurement Tools

Whenever available, measurement instruments should be calibrated with procedures developed by the National Institute of Standards and Technology. Instrumentation accuracy specification is acceptable, however instruments provided with multi-point factory calibration is optimal. For long-term (12 months or more) monitoring projects, a six-month to 12-month recalibration should be conducted. Data logger memory length and ideal data resolution should be considered when specifying equipment in order to optimize the cost of the equipment versus the labor required for mandatory data pulls over the project's intended monitoring period.

The functionality and accuracy of monitoring equipment should be verified before installation. This can be accomplished by comparing instantaneous measurement values with the outputs of the data loggers. For example, if monitoring energy use, instantaneous current and voltage measurements can be taken and compared to the outputs of an energy logger to make sure that the logger is installed correctly and recording accurate data. Verification can also be executed by comparing logger outputs to a calculated resource consumption to make sure values are within an expected range.

Types of Metering Tools, Sensors and Data Collection Equipment

There are many types of metering tools, sensors and data collection equipment available on the market. Table 1 includes a partial list of tools and sensors applicable to measurements often conducted as part of a Program demonstration. Detailed information on each type of device is readily available in the public literature.

Table 1: Examples of Meter tools and sensors

Temperature Thermometer Thermocouple RTD	Humidity Dew/frost Psychrometer	Air Flow Pitot Tube Flow nozzles Hot-wire anemometer
Liquid Flow Flow nozzle Turbine Vortex Orifice	Air Pressure Manometer Pressure gauge Pressure transducer Pressure transmitter	Hydraulic Pressure Manometer Pressure gauge Pressure transmitter Pressure transducer
Electrical Power Watt-hour meter Watt transducer	Electrical Current Clamp-on amp meter Current transformer	Electrical Voltage Voltmeter Multimeter Potential transformer
Illuminance Illuminance meter	Occupancy CO_2 meter Ultrasonic dectector PIR dectector	

Source: California Lighting Technology Center

Several measurement types should utilize only certain tools.

- True RMS power and energy metering should be used over current and voltage measurements unless the load is purely resistive
- RTDs or thermocouples should be properly selected based the expected time in the field and severity of conditions

Human Factors Assessment (Ergonomics)

Ergonomics, sometimes called "human factors," is the study of designing equipment, devices and systems that aid the human body and its cognitive abilities. The discipline is concerned with understanding interactions between humans and other elements of a system. For the Program, the interest is primarily in the interactions between occupants and the systems that are being demonstrated. For a more in-depth review of ergonomics as a field, please consult Appendix A.

Determining the human response to a system is called an ergonomic assessment. This assessment comes in many forms and can be executed many times. Common assessment periods may span: new construction of a building, before and after system upgrades, observed problems with systems and the future revisiting of a completed project. Typically, an assessment will include a cross–section of individuals using a technology or involved with the purchasing process. These individuals can typically be classified as employees or service users, professionals who design the system and decision makers. There are a wide range of assessments that can be used to develop a complete understanding of the environment or system. The most common are interviews, surveys and field research.

Common Types of Assessments

Direct interviews allow the direct selection of the intended audience and for complete and well-explained responses. This methodology provides the richest data because it allows the surveyor and the surveyed to explain and clarify questions in real time, increasing the accuracy of the collected data. Direct interviews are time consuming and often costly. The interview requires interviewers who are trained and are confident in their ability to provide a neutral tone, phrasing and appearance. Too much rigidity in the interview process can reduce the benefits of the interview and make the process feel more like a survey without much direction or conversation. Conversely, too much flexibility can result in large inconsistencies across interviews such as providing too much support on certain questions or potentially leading interviewees.

Surveys are an excellent way to gather large amounts of information from many people in a short period. They are best when seeking to gain a high level of understanding of the attitudes and characteristics of a large group. By their nature, surveys are a reliable method of inquiry because they standardize the delivery of questions, resulting in reliable consistent data. While surveys provide a number of advantages, they are also inflexible tools. There is no additional clarification for questions, so when respondents are confused or need more guidance to answer a question they are unable to receive it. Surveys do a poor job of uncovering trends or results that are not explicitly stated. For example, physical discomfort from the climate in an office may be caused by poor heating and cooling systems, hot lamps from lighting or poor thermal glazing from fenestration. If the surveyor does not think of these options, and clearly explain them, the respondent may, based on their limited knowledge of the systems in their space, express a frustration directed at any one of these causes of discomfort or none at all.

Field research consists of the observation and interaction with people in their natural settings. This method strives to fully understand the daily lives of the people they observe in the space where the assessment is being carried out. Field research is well suited to answer the "how" of why an event occurs. Researchers are able to observe, theorize and test their theories based on interactions with the people in the space in question. Field research is a time-consuming process and requires that researchers be present in a space over a period of time. However, it does provide an in-depth understanding of how events occur within a space.

The Assessment Process

The purpose of any ergonomic assessment is to ensure that people are placed in an environment where their physical, psychological and social well-being is not affected by the building system. The assessment process typically looks to establish a baseline with an initial assessment, then follow up with an installation assessment and post-installation assessment. The subsequent assessments allow the demonstration team to determine the extent of the disruption associated with the installation process and gauge its effect on the post-installation feelings of the space occupants.

During the initial assessment, the goal is to understand three major components:

- The *environment* under evaluation, often a building
- The *systems* in place, e.g. heating, cooling, lighting, fenestration, insulation, etc.
- The *people* within that space that interact with its systems

Environmental aspects of the assessment appear to be simply a physical analysis of the space, but it is deeper than a simple geometric description of a space. Environmental factors include how the space is divided into functionally distinct sub-spaces by the occupants of the space. For example, the space could be an open office, but certain cubicles could be left open for the reading of plans, while others for one-on-one meetings.

Consider all the systems that are present in a space, as well as how the occupants interact with them. Often times, there are systems in a space that users are not aware of or do not interact with. Existing systems may impact the new technology or vice versa. Occupants will often have opinions on the systems which they interact with daily. Capturing these opinions and these needs is the most important part of an assessment.

People within the space accounts for why types of people (professionally or otherwise) use the space. Back to the example of the open office, any number of employees and management may utilize the space. Employees with different work types will utilize a space differently. For example, an architect will have different needs and goals for his space than an accountant. Understanding who the people in the space are and the needs associated with their professional requirements will help shape a demonstration as well as establish a baseline of needs.

During the installation assessment the goal is to understand if and how the inconvenience of the installation process affects occupants. Additionally, if that inconvenience affects the feelings or opinions of the retrofit system in a positive or negative light (independent of the actual system functionality).

Post-installation evaluation is split between an initial evaluation and long-term verification. The initial evaluation is aimed at seeing how the system is adopted while the long-term verification is aimed at how the system is ultimately received by its users. Topics of interest include:

- User feedback on the project process
- User understanding of the system
- Installation issues (issues that stemmed from the installation process)

The long-term verification ergonomic assessment is intended to re-evaluate and potentially adjust the demonstrated systems. During this time period, the effectiveness of the system is measured and evaluated against stated objectives and in maintaining user comfort. Topics of interest include:

- Does the project still function properly?
- Are occupants affected in new ways?
- Have accommodations for impacted people been successful?
- Are users happy with the project?

Chapter 4
Conducting a Study

Assessments conducted under the Program produce complete and detailed technology reports that may be used by the Energy Commission, utilities and other stakeholders as part of their CASE initiatives. This section describes design, implementation and documentation requirements for a CASE quality demonstration project. It includes recommendations for the selection of technologies and sites; assessment requirements for existing and proposed measures; and technology installation considerations. In general, designing and implementing a study will include the following activities.

1. Pre-demonstration market and economic evaluation (Chapter 2)
2. Site Selection
3. Technology Selection
4. Assessment Plan Development
5. Benchmarking (Chapter 3)
6. Technology Installation
7. Post-retrofit Measurement and Evaluation (Chapter 3)
8. Outcomes and Reporting (also Chapter 5)

Site Selection

Due-diligence evaluations must be conducted on any potential demonstration site to ensure the site selected will meet the project's needs. A site evaluation will determine the likelihood that a particular location will be able to support the demonstration project throughout each of its phases. Site evaluations should begin as soon as a demonstration measure (product or practice) is identified or selected and before host-site agreements are put in place. The demonstration team's experience working with the demonstration technology will often dictate the speed at which effective site evaluations can be conducted. At a minimum, the following things should be investigated and understood for any potential demonstration site:

- Site's ability to accommodate construction/demonstration
- Existing equipment and systems
- Site accessibility
- Impact on a site's existing operations
- Impact on surrounding facilities or communities
- Land use restrictions
- Environmental impacts
- Permit requirements
- Representative of typical facility, market sector, or installation

The selection of a demonstration site and demonstration size should result in a demonstration project that is fully documented and, at a minimum, clearly representative of its performance at that site under all anticipated operating conditions. Ideally, a site that is representative of typical, anticipated use across a set of sector-specific facilities is best. For select technologies, it is advantageous to operate and monitor the incumbent and the emerging technologies in side-by-side installations. Sites with the ability to accommodate this should be considered when such technologies are being demonstrated in order to more accurately capture the energy savings attributed to the technology efficiency versus the user behavior and to better determine the variance in energy savings based on user behaviors.

Sites with minimal accessibility, costly and non-representative permitting requirements, or other atypical constraints should be avoided. Documentation on each item noted above should be provided for the final site selected.

Site's Ability to Accommodate the Demonstration

Certain technologies, specifically HVAC technologies, are designed with a specific climate zone(s) in mind. A cooling system designed for the dry warm weather of climate zone 14 (Death Valley, CA) would not be as effective, or not effective at all in climate zone 3, which makes up much of the San Francisco Bay Area. In addition to climate related limitations, the physical environment of a building or space may not reflect the required installation or operating conditions for a given technology. A good demonstration site will be able to accommodate the demonstration and provide an environment suited for installation of the demonstration technology.

Existing Systems

Most sites will have an existing system, which the demonstration aims to replace. The functionality and efficiency of the existing system will have a large effect on the results of the demonstration. These effects range from setting an arbitrarily high or low baseline (when compared with standard practices) or unrealistic installation costs. The ideal demonstration site will have an existing system, which is on par, from an efficiency standpoint, with the average Californian system. It also will not include any a typical removal or disposal costs, which would not be representative of systems currently installed in California buildings.

Site Access

Most host sites will have specific access requirements for some or all of its demonstration spaces. Access constraints may exist at the site, building or individual space level. For example, mechanical rooms that provide access to HVAC systems and electrical panels may require prearranged access to room keys or the assistance of site staff to access the space. In other cases, entering a buildings or campus may require special identification or accompaniment by site staff. Some facilities or sites, such as military bases, may require a submission of personnel background information prior to gaining approval to access the site. Regardless of the level of security or control, failure to identify and plan for these kinds of accessibility requirements can result in delays related to site visits, equipment installation, monitoring and verification activities and access to building occupants for surveys or other subjective evaluations of the demonstration technology. Always include scheduling contingencies for sites with access requirements to ensure projects are completed on time. Always document the access requirements for the final site selected.

Impact on Existing Operations

Site access and impact on the existing operations of the site are typically inversely related. For some sites, the hours of use are strictly restricted while others are open to the public 24 hours a day. Depending on the space type and its use, a demonstration may or may not be feasible in the space. For example, offices are typically utilized between the hours of 8 a.m. and 5 p.m. As a result, the installation of demonstration technologies and monitoring and verifications activities can be carried out while the space is unoccupied and there is minimal impact on the host site. Other building types will have drastically different usage hours. For example, some big box retail stores are open 24 hours a day. A demonstration at a site that operates for most hours of the year will be difficult to carry out without significant impact on existing operations. Additionally, attempting to navigate a space that is in use to establish pre- and post - retrofit site conditions will be difficult because of regular interruption by customers and site personnel. Other sites difficult to consider as a host site are those where the space itself is off limits to personnel. These sites include factories and research facilities where contamination or real physical danger to site occupants prevents access without directly impacting the existing operations of the space. For example, some biological research facilities cannot have their research interrupted in order to carry out the parts of a demonstration. As a result, it may be impossible to effectively carry out monitoring and verification activities as well as execute the demonstration installation.

Impact on Surrounding Facilities or Communities

Demonstrations often have primary and secondary audiences affected by the project. For example, a retrofit of parking lot lighting at a local park directly affects the visual comfort of local homeowners. The installation of the luminaires could reduce the number of spaces in the parking lot resulting in parking overflow and potential traffic issues at adjacent locations. Other demonstrations can result in noise pollution from the project installation or the demonstrated product. For example, the installation of large HVAC units that operate throughout the day could have an adverse effect on the quality of life of nearby neighbors. In some cases, the demonstration may improve the quality of an underused facility, thus changing its future occupancy. The increased use of a community center because of a renovation could result in traffic that local roadways weren’t built to handle. When choosing a host site, take into account the potential traffic, noise and occupancy effects that the retrofit could have on the space and its surrounding facilities or communities.

Conversely, take into account the impact that the existing site can have on the technology demonstration. For instance, systems that rely on network communications can be impacted by new antennas installed in the demonstration area or surrounding area. For applicable technology demonstrations, understanding if the host site has plans to implement such upgrades during the monitoring period of the demonstration will contribute to the site's appropriateness as a representative demonstration site.

Land Use Restrictions and Environmental Impacts

Land use restrictions may prevent the installation and demonstration of some technologies at certain facilities. Local ordinances and zoning requirements should be reviewed before selecting a host site. In addition, demonstration of certain technologies may require environmental impact studies to ensure that the technology does not disrupt the surrounding area. An environmental impact study may result in water-use or traffic restrictions at the site, which could add unnecessary cost and complexity to the demonstration. Avoid sites where these types of restrictions may be in place, unless the site is representative of the market sector.

Host Site Agreements

Host site agreements are legal documents intended to protect the rights of the host site and the group carrying out a demonstration. Such agreements are required for any demonstration project funded under the Program. Each document will be unique, because each technology and host site is different. At a minimum, they all should address the following six items:

- Project scope: Intended to educate project participants on the basic tasks and goals of the demonstration. This can include a description of the demonstration technologies, the anticipated benefits and risks, and location of the installation.
- Responsibilities of both parties:
- Project duration: duration of the project should include a written timeline and preferably a Gantt chart outlining all tasks and their expected start and finish dates. This allows host site personnel to notify space inhabitants and adjust schedules and expectations during installation periods.
- Site access: Clauses having to do with accessibility provide both parties clear guidelines on how and when the demonstration can be accessed and prevents the interruption of work within the demonstration space.
- Project data, outcomes and publication rights: Specific rights are outlined as to the ownership of the data obtained through the monitoring and verification activities meant to quantify the effects of the retrofit. It should also clearly outline the rights of the host site and or the demonstration group to publish the data or related information about the demonstration.
- Liability: Liability issues include the needs of contractors to meet host site or program sponsor requirements as well as questions as to who will be responsible for the replacement or repair of the retrofit technology should it fail during the M&V timeline or even afterwards.

Technology Selection

Demonstration technology selection may occur in one of two ways. Specific products may be preselected for demonstration based on Energy Commission determination, manufacturer, or other stakeholder input and analysis. In this case, the specific demonstration product, and often manufacturer, is known prior to the start of the CASE-QDP project. Conversely, the specific demonstration product may not be known prior to the start of the project, and only the type of product/class/category (generic) may be identified for demonstration. In this case, the demonstration team can use a thorough market analysis (Chapter 2) to select products appropriate for demonstration. Whichever path is followed, once a specific product is identified for demonstration, a detailed description of the technology must be prepared and included in project reports.

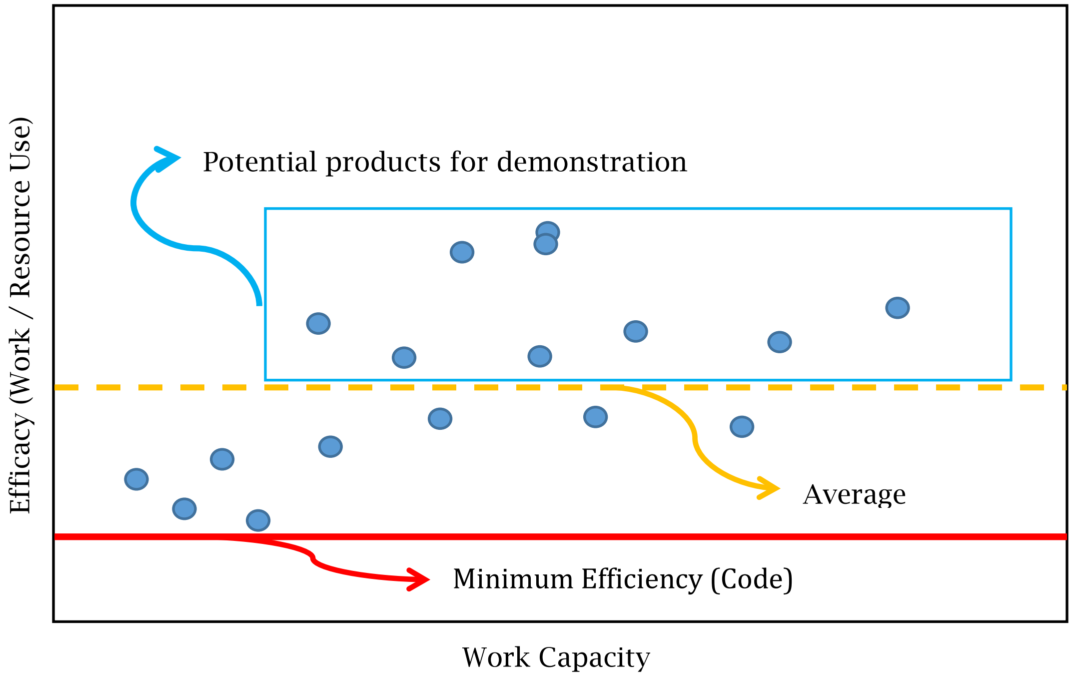
Documented information will vary based on the technology, as will the importance of specific performance and/or product details. Demonstration teams should obtain and provide all available product literature, which will provide critical information for proper documentation of individual measures. The following information, at a minimum, should be provided for any CASE-QDP demonstration technology:

- Product name
- Product serial number / Part number
- Product manufacturer
- Date of purchase or acquisition
- Manufacturer's product specification sheets
- Manufacturer's product installation sheets
- Product warranty
- Product maintenance information
- List of comparable products

Comparable Products or Practices

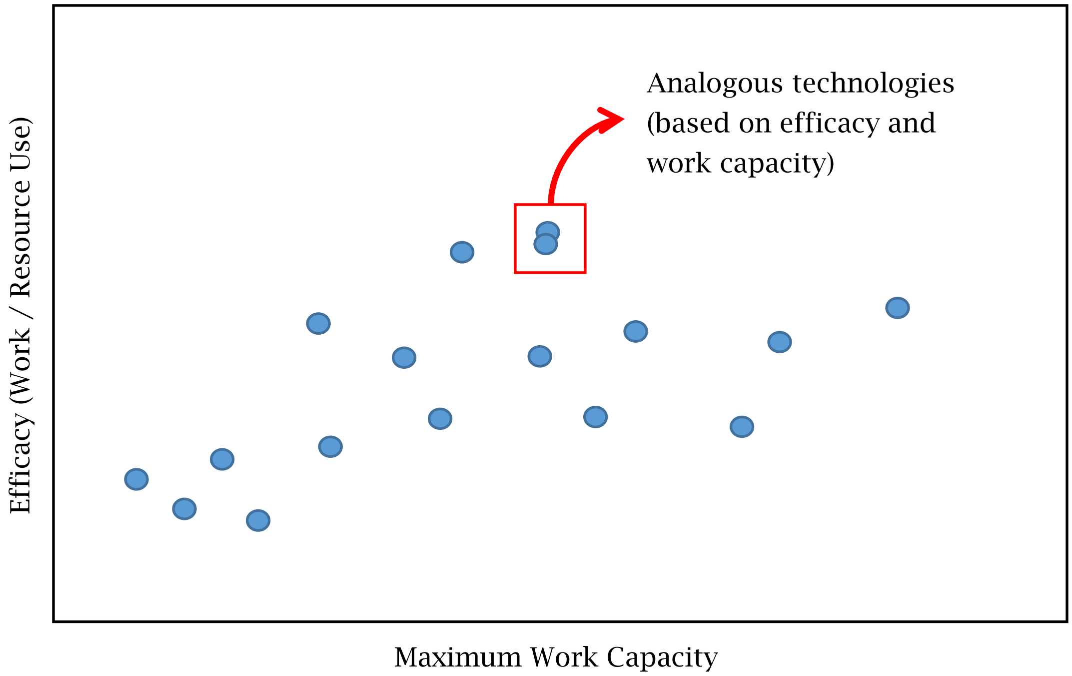
Products or practices which provide resource savings beyond current code requirements are often good targets for Program demonstrations. Selection of highly-efficacious products or practices as compared to existing products or design standards, can be aided by good market research. Given the existing landscape of technologies and practices, a selection of products and their corresponding product efficacies and maximum work capacity can be graphed. Using this information, an average product efficacy can be calculated for each product class, noting products that exceed this value may be appropriate for inclusion in the Program.

Figure 4: Product analysis graph of work versus efficacy (example only)



Many products may be appropriate for demonstration. However, a potential demonstration technology may have an analogue version which can do the same amount of work as other similar products at the same or similar efficiency. In these scenarios, it is not recommended to demonstrate multiple technologies unless there are distinct differences or performance claims that would set one product apart from another. Under certain situations, multiple products of similar type may be demonstrated to validate the average performance of a class of products or systems; however, duplicative demonstrations should generally be avoided unless the need or value of doing so is clear and documented.

Figure 5: Product analysis graph - analogous technologies (example only)



Product Availability

Often, emerging technologies are not readily available through standard commercial channels. As a result, only a small quantity of a product may be currently available. When this is the case, there are two major questions to answer. First, by the time the next code implementation occurs, will this product be widely available so Californian consumers could easily purchase and install it? The second question is whether the size of the demonstration, based on current product availability, will provide an accurate representation of the products performance and value. If the answer is no to either of these questions, then the product may not be appropriate for inclusion in the Program at this time.

In general, pre-commercial and under adopted technologies are most appropriate for the Program. A pre-commercial technology is defined as a technology that will be available in the marketplace within six months of the current date, has limited or no independent performance data or validation and has seen limited demonstration. Additionally, under adopted technologies are commercially available, but have seen limited adoption, and/or limited or no independent evaluation.

Positive Life Cycle Cost

Technologies poised to affect the market and experience meaningful market uptake will typically have a positive life cycle cost – net present value (NPV). The NPV takes into account the effect of inflation on money in the future, in effect discounting future values. The sum of all future cash flows over the life of the product or system, is the

NPV. If the NPV is positive, then the purchase and installation of the technology has a positive effect for California consumers, delivers resource savings, and should be pursued. One caveat exists for this rule: if a measure's initial cost is expected to decrease to a point where the NPV goes from negative to positive due to reduction in tooling costs, increased consumer demand driving volume and lowering prices, or increased efficiencies due to new technology development, the measure may still be a good candidate for demonstration.

Additionally, when a portion of a technology system can leverage pre-existing components of incumbent system, it is recommended that the end-of-life and maintenance impact be included in alternative NPV calculations to inform the technology selection.

Developing a Demonstration Assessment Plan

Development and adherence to a detailed, demonstration assessment plan is critical to the success of a technology demonstration project. The plan details the elements included in benchmarking, post-retrofit evaluations, system modeling, and data collection and reporting. The following information is intended to guide Program participants in the successful development of demonstration assessment plans that include both objective and subjective evaluations. Subjective evaluations or human-factor assessments are highlighted at the end of this section; however, more detailed information may be found in Appendix A.

Plan Components

- Project summary and assumptions
- Description of M&V activities
- Description of calculations
- List of monitored devices or systems
- Monitoring procedure for each device or system

Benchmarking

The majority of variables directly associated with the resource use of the demonstration technologies should be noted and monitored as described in the demonstration plan. Other variables should be recorded. Examples of these variables include items such as the number of failed lamps in a lighting demonstration space or the existence and condition of shade canopies affecting fenestration projects. The following items should be investigated and recorded as part of a CASE-QDP project.

Site

The most obvious set of baseline data relates to the demonstration site. Site conditions of importance typically have some potential correlation to energy use as it pertains to geographic location and occupancy. Examples of site-specific conditions of note include the following items (some are also described in the Baseline Conditions section of this report):

- Geographic location and climate zone
- Building type, envelope type, fenestration, size, and orientation
- Building use(s) and a breakdown of building uses in the case multi-use facilities
- Landscaping, such as shade trees, that may affect systems
- Traffic that may affect occupancy
- Hours of use

Existing Systems

Also as important as the site-specific data is information on the baseline systems which will be retrofitted during the demonstration process. Notes should be taken on the existing systems and if possible, some insight into the use of the systems or their area of performance. If the system in question works directly or indirectly with other systems, for example an HVAC system, which works with a building management system, data should be collected on the interaction between the systems. Content related to the existing systems should include:

- Make/models of incumbent technologies
- Number installed
- Details on locations/orientations of each of the units
- How the systems are powered
- Details on sensors (locations) and controls
- Maintenance records
- Existing condition
- System interaction with other building systems or controls

System Operating Profiles and Resource

When monitoring incumbent technologies, understanding their operation is an intrinsic part of developing a resource use profile and calculating energy use. Important details to note include start up and shutoff time, set-points, and occupant adjustments. This information can be gleaned from the technology itself, but communicating with building occupants or maintenance staff can provide information that would be otherwise impossible to find out. Details on methods to determine energy and demand savings are provided in Chapter 3. A usage pattern can span anything from an hour to a year and is often most easily understood by looking at different time segments of the project's M&V data. Characterizing resource usage of a technology allows the application of TDV, but also allows the effective application of controls and an in-depth understanding of building use. When developing usage patterns, graphing the data is often the first step in understanding the systems' usage. The graphic representation of data allows for a simpler recognition of patterns and trends. By viewing M&V data in different time segments such as days, weeks, months or seasons it is often easier to observe and understand resource usage trends. For example, in retail applications, energy use would be expected to be constant throughout the day with some baseline load when the retail space is closed for signage and window displays.

The graphs below are examples of system operating profiles in different time segments. There may be characteristics that repeat during certain time segments, whether they are days, weeks, months or throughout the year. Seasonal weather changes may result in very large changes in resource consumption.

Figure 6: Energy Use over 24 hours (sample only)

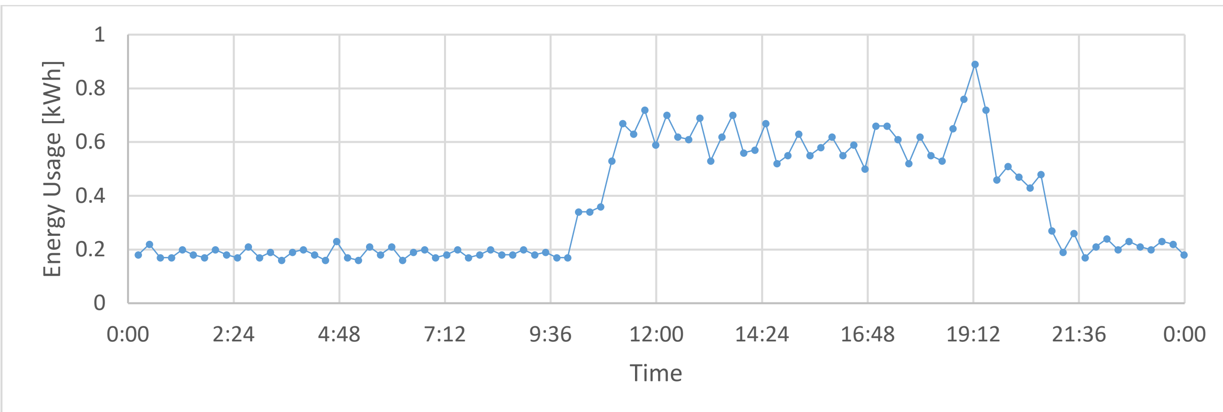


Figure 7: Energy Use over a 7-day period (sample only)

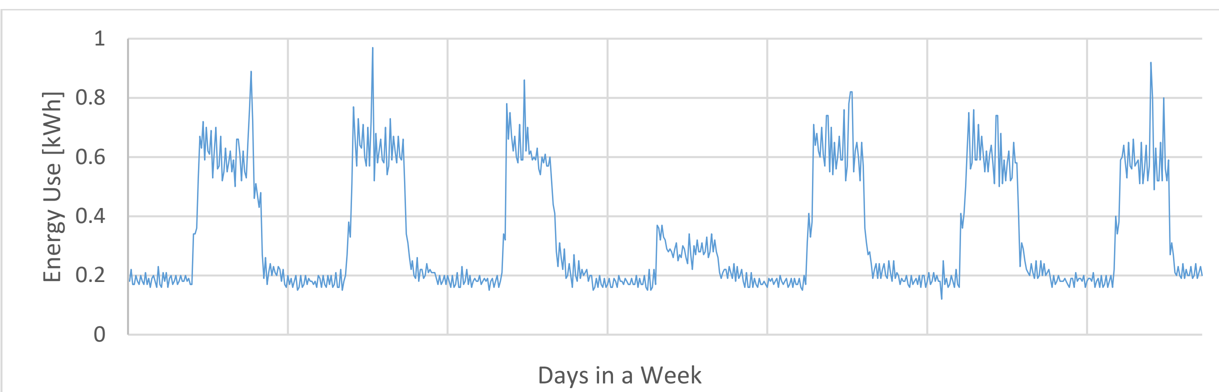
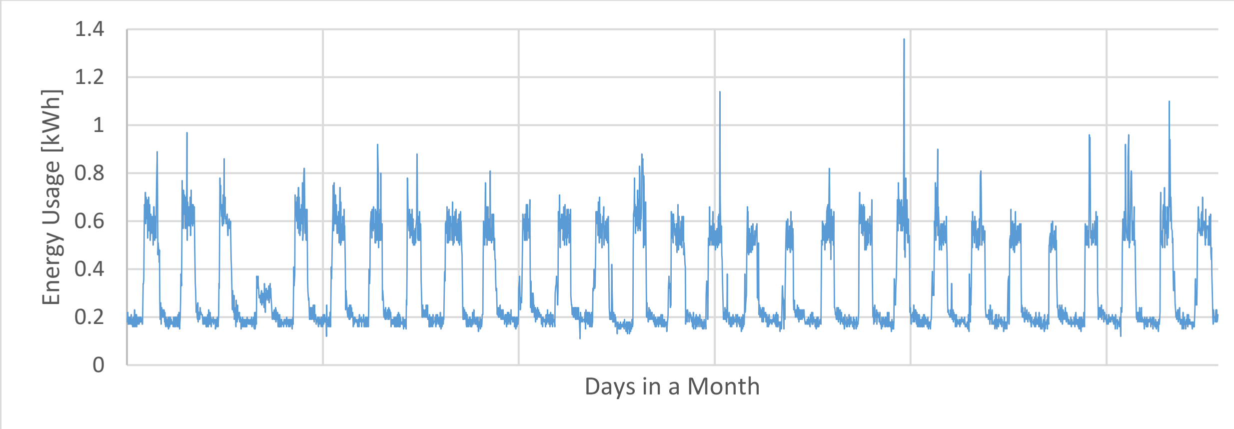


Figure 8: Energy Use over a 30 - day period (sample only)



Technology Installation

Technology installation is a milestone in a Program demonstration. It will provide host-sites with a tangible outcome of their investment in and support of the project. Installation usually marks the successful completion of benchmarking activities. There are many important aspects of installation, however, that must be considered and processed before the technology is ever installed at the host-site. While each project will have its own unique installation requirements, several major topics for consideration are discussed below.

Technology Ownership

Technology ownership is a negotiating tool when finding an amenable host site. If the agreement with the host site includes ownership of the technology, it is recommended that the ownership be transferred to the host site after the monitoring period is completed in order to reduce the number of variables impacting the validity of the study.

The technology should be delivered to the host site if there are no modifications required to the equipment and if there is ample short-term storage space at the host site facility. Otherwise, the technology should be delivered to the contractor or project team for storage and handling until the scheduled installation can take place.

Contractor Selection

Contractors with expertise in the demonstrated technology type is recommended to perform the technology installation. For example, if the demonstration is of an advanced lighting controls system it is recommended that the contractor selection criteria include a requirement for the installer to be certified through a recognized education program. Previous experience with the exact technology should be prioritized.

To create a competitive environment and ensure best use of resources, at least three bids from competing contractors are recommended to be collected before choosing the contractor for the project. It is recommended that the installation labor be funded by the project team. Potential benefits of this structure include streamlining the communication and demonstration chain-of-command in order to retain as much ownership of the demonstration as possible over the duration of the monitoring period.

Commissioning

The commissioning requirements of each technology type varies from manufacturer to manufacturer. If the demonstrated system manufacturer provides commissioning in a start-up service, it is recommended that the demonstration use this service in order to be as representative of an installation as possible.

It is recommended that a one-week period of monitoring be conducted in order to verify the system is functioning as intended after the commissioning process (see Troubleshooting section).

Re-commissioning of the system for monitoring of the system running in alternate modes is a typical reason for additional site visits being made by the commissioning team. In order to budget the project accurately, it is recommended that the project team fully understand the costs of additional site visits by the commissioning team.

Troubleshooting

After the initial start-up and commissioning of the demonstration technology, it is recommended that a one-week period be scheduled for a troubleshooting phase of the technology installation. During this phase, one-time and continuous measurements of critical performance variables should be collected and analyzed to determine if the system is operating as intended. For example, if the demonstrated technology is operated on a known schedule the troubleshooting phase should confirm that the actual operation of the technology is following the expected schedule.

Anomalies identified during this phase may result in the replacement of select technology components, re-commissioning of the technology, or modification of the monitoring and verification solution implemented at the site. This information is to be documented in the final report.

Operations and Maintenance

After the demonstration monitoring period is complete, it is recommended that the project team provide the technology system owner with operations and maintenance guidance. For example, understanding how to use maintenance alert features of networked control solutions can increase the user satisfaction and reduce the traditional maintenance costs associated with the incumbent system. Additionally, if the technology system requires more operational or maintenance than the incumbent system this should be transparent to the new system owner in order for their facility to remain functional. At a minimum, the user guide for the new technology should be provided.

Outcomes and Reporting

Post-Demonstration Project Review

Following the completion of the project, the demonstration process should be reviewed. Ideally, these reviews happen throughout the demonstration process to keep the project on schedule and within budget. The most critical review compares the original goals of the demonstration to the outcomes. Compare the plan to acquire data what occurred in the project and review the processes associated with the data capture. Often, our understanding of the technology or installed space changes over the course of the project. Based on this new understanding, it is important to reevaluate whether the data capture process and technology selection is still relevant and helpful in reaching project objectives. Based on initial data from the M&V equipment, examine the initial results to ensure they are logical. Issues with M&V equipment can be discovered by looking at initial measurement readings and determining whether the results are consistent with the current understanding of the system.

Lastly, the project review must determine whether the results that have been logged, or are being logged, are likely to change. Will usage rates change during the year? Will this have an effect on the resource consumption of the technologies? Will we need to carry out multiple monitoring periods to get an accurate understanding of the resource usage of the demonstrated technology? Often, demonstrations will be monitored for at least a year to develop an accurate understanding of the incumbent technology and retrofit technology. This accurate model of the technologies allows a fair comparison between different systems.

To summarize, some questions that should be asked during a post-demonstration review are:

1. What was the purpose or goal of the demonstration?
2. What data did we want to capture?
3. What was the process that would allow us to get this data?
4. Does that process still make sense?
5. Did we capture the data we needed?
6. Do the initial results make sense?
7. Will these results change? Why or why not?
8. Should we return to recalibrate the results to receive more realistic data?

Applying Study Results

A goal of a CASE-QDP assessment is taking the data gathered in the study and applying it more broadly to understand potential statewide energy savings that would result from its implementation. Quantification of the benefits of energy conservation measures across sectors can be achieved in many ways, but they always include the characterization of the specific market sector in question and its related energy savings. Once the energy consumption of a given practice or technology is determined, calculating the potential energy savings of the energy conservation measure can be calculated either by percentage or by vintage.

Chapter 5
Program Reports and Project Documentation

Final Demonstration Report

Final demonstration reports are meant to capture the relevant details and analysis of the demonstration concisely. Standard report sections include an executive summary, a summary of the incumbent installation, retrofit technologies, market analysis, and an identification of the key stakeholders. Information relevant to the sections should be included in appendices. The information below provides more details about sections that should be in the final report.

Executive Summary

The executive summary presents the project to the reader concisely. It should be a brief summary of the project's purpose and how each of the report sections supports the fundamental goal. It should convey the project objectives, methodology and outcomes.

For the purposes of the Program, the summary should address and clarify a number of issues, regardless of the type of demonstration project:

- The specific market to be addressed needs to be identified and described. Who are the users and what are the incumbent technologies and products?
- Explain the impact that the proposed changes are likely to have on the market. Once the variables are identified, likely through mathematical modeling, the summary needs to discuss how the code change will alter the equation both mathematically and in real-world terms.

Technology Background

Demonstration Measure Description

Provide a general description of the demonstration technology or measure. Describe the physical and performance characteristics of the technology, its benefits as compared to existing technology/practice and its target market sector.

Demonstration Objectives

This section describes the requirements that should be included in a description of CASE demonstration objectives. It should give instructions on the type of information and results to include (quantifiable results vs. task descriptions).

Existing State-of-the-Art

CASE measures must include a description of the existing practice/measure that the CASE technology/measure is designed to replace or improve. This section provides guidelines on what to document for the existing state-of-the-art in product/practice as compared to the CASE measure. Specific details are provided below:

Technology or Process Description

This section provides instructions on how/what to describe for the existing product or practice (with respect to CASE measure).

Market Profile / Availability

This section provides instructions on how/what market information to present on the existing state of the art (with respect to the CASE measure).

Key Stakeholders

This section provides instructions on who to consider as key stakeholders. It provides recommendations on the types of information to include about each stakeholder such as their role in the CASE process, their role in product/measure commercialization, etc.

Interim Report Format and Requirements

Interim reports are typically provided for key stakeholders at set dates throughout the project process. Major interim reports should use the Energy Commission style manual and template.

Progress Reports

Progress reports should follow the Energy Commission style manual. Monthly or quarterly reports are acceptable. Reports should include the following sections in addition to photographs and other evidence of project progress:

- Description of planned activities for the period
- Description of actual activities completed for the period
- Discussion of progress relative to the project plan
- Discussion of significant problems or changes to the project plan
- Description of planned activities for the next period
- Status updates for deliverables and milestones
- Summary of financial status of the project

Participant Agreements

For projects funded through the CASE-QDP, participant agreements must be executed between the demonstration host site and the team conducting the technology demonstration. Participant agreements should include the information described in Chapter 4.

Test Plans

Test plans should address each of the applicable elements detailed in Chapter 4 of this manual. Define all technical terms and provide a list of acronyms with definitions.

Technical Specifications

For all demonstration technologies, copies of product specifications, instruction sets, installation guides, commissioning guides, and other documentation must be provided. In addition, technical literature and product specification sheets must be provided for data collection and measurement equipment. This information may be provided as appendices to interim or final project reports and test plans.

Budget Template

Budgets for each CASE-QDP sponsored project should follow the most recent budget template provided by the Energy Commission. More information may be found here: http://www.energy.ca.gov/contracts/pier.html.

Appendix A-1: Human Factors Assessments

Ergonomics, sometimes called "human factors", are a part of a multidisciplinary field incorporating contributions from psychology, engineering, biomechanics, design, statistics, operations research, and anthropometry. Human factors are used in studying designing equipment, devices and systems that aid the human body and its cognitive abilities. The terms "human factors" and "ergonomics" are often used synonymously.

Ergonomics is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system. The profession applies theory, principles, data and methods to optimize human comfort and system performance. Practitioners of ergonomics contribute to the design and evaluation of tasks, jobs, products, environments and systems in order to make them compatible with the needs, abilities and limitations of people.

Physical

Physical ergonomics is concerned with human anatomical, anthropometric, physiological and biomechanical characteristics associated with physical activity. This includes working postures, materials handling, repetitive movements, work related musculoskeletal disorders, workplace layout, safety and health.

Cognitive

Cognitive ergonomics examines mental processes as they affect interactions among humans and other elements of a system. This can include mental workload, decision-making, skilled performance, human-computer interaction, human reliability, work stress and training as these may relate to human-system design.

Organizational

Organizational ergonomics evaluates the optimization of sociotechnical systems, including their organizational structures, policies, and processes. Examples of organizational ergonomics include communication, crew resource management, and work design, design of working times, teamwork, participatory design, community ergonomics, cooperative work, new work paradigms, virtual organizations, telework, and quality management.

The focus of an ergonomics assessment is to improve performance and wellness by designing a system that better integrates the human into the system. The goal of the assessment is to design a building system that fits the environment to the person, rather than selecting people to fit the environment. With a better fitting environment, individuals are better able to contribute to performance. Many people suffer from environments at work and home incompatible with their needs, abilities and limitations, which affect their safety and welfare as well as that of organizations and societies they are a part of.

Advanced technologies can make our buildings more efficient. However, overly ambitious or just poorly thought out endeavors can overlook human factors risks. Neglecting these risks can have serious negative effects. An ergonomics assessment is an evaluation of the impacts caused by a technology, system, or event on a person or organization. The goal of the assessment is to ensure a good fit between the person and the technology or system, so the user will use the technology in the way intended and to use the technology to maximize energy savings

Doing this successfully requires ergonomists to consider:

1. The activity being performed and the demands on the user
2. The equipment used and how appropriate it is for the task, and
3. The information used and how it is presented, accessed, and changed

Successfully evaluating the ergonomic factors present in an environment ensures that the individuals and organizations in that space maintain the highest possible levels of wellness, health, safety, and efficiency.

Assessment Timing

In almost any situation an ergonomics assessment provides benefits to the individual or organization being evaluated. Common assessment periods include:

1. During new construction of a building
2. Before and after an upgrade to a building system
3. When there are observed problems with a technology or system
4. Future revisiting of a completed project

Involved Persons

Employees, product/service users: Those who are part of the system and who are directly or indirectly affected by its design and performance.

Professionals: Engineers and specialists who contribute to the design of the system based on their specific professional backgrounds. They focus on design by fitting the environment to humans.

Decision makers: Those in charge of the system design, the purchase of the system and its implementation.

Common Types of Assessment

The methods outlined below are commonly used when performing an ergonomics assessment. The ultimate goal for these strategies is to develop a complete understanding of the environment or system being changed. In this way, the impact on the people within that space can be evaluated and minimized.

Ethnographic analysis: Observing the uses of technology in a practical environment. Best used early in the design process.

Focus groups: Qualitative research process in which one person facilitates discussion about the technology or process being evaluated. This can be on a one-to-one basis or in a group session. It can be costly and, due to the small sample size, can be subject to individual biases.

Iterative design: Also referred to as prototyping, this process involves users at several stages of design in order to correct problems as they emerge. Trends among users are analyzed and products or systems are redesigned.

Meta-analysis: This technique evaluates a wide body of existing data or literature to identify trends in order to aid design decisions.

Surveys and questionnaires: Surveys and questionnaires can be quickly and easily administered to a large group of people at relatively minimal costs, enabling researchers to gain a large amount of data. The validity of the data depends heavily on how well the survey or questionnaire is crafted.

Task analysis: This is a qualitative and observational process that attempts to fully describe all of the tasks taking place within a system.

User analysis: This process helps design for the attributes of the intended user by establishing defining characteristics of each user type. A user analysis attempts to predict the most common users and the characteristics that they have in common.

Methods analysis: The process of studying the tasks that an occupant undertakes within a system using a step-by-step process. Each task is broken into smaller and smaller steps until each basic task is described.

Time studies: This process determines the time required for a person to complete each set of required tasks.

Work sampling: This method samples a person’s job at random intervals to determine what proportion of their day is spent on a particular task.

Frequently Used Methodology

In-depth Interview

Talking directly with workers, users, or occupants has advantages, but can also present challenges. You will be assured that the responses are from the intended audience, as you select them, and are given the opportunity to probe for more complete or better-explained responses. This method tends to yield the richest data. Listening to respondents describe what is meaningful, useful, intuitive, or important in their own words can provide details or new insights. In-depth interviews are flexible allow for opportunities to explain or clarify questions in real time, increasing the accuracy of collected data while still staying within the structure and scope of a well-designed interview protocol.

Scheduling and conducting the interview takes times, however, making this method very costly. Training interviewers may be necessary to ensure that the interviewer has enough knowledge of the subject matter and feels confident in his or her ability to conduct the interview. In addition, interviewer error or bias must be understood and avoided. Changes in tone of voice or the phrasing of questions, or even the gender or appearance of the interviewer, can lead to errors and bias. Detailed interviews produce a huge amount of data in a short period of time, making analysis difficult. Too much flexibility can result in inconsistencies across interviews.

Survey

Surveys are an excellent way to gather a large amount of information from many people in short period of time. Surveys are very cost effective, especially when administered digitally. Because surveys allow researchers to collect data from large samples for a relatively low cost, they are excellent tools for probability sampling techniques, which determine the likelihood that an event might occur. Surveys are the best tool to use when one hopes to gain a high- level understanding of the attitudes and characteristics of a large group. Well-crafted surveys are also a reliable method of inquiry because of the standardized delivery of questions, phrased in exactly the same way. This produces reliable and consistent data. Field Research

Field research is observing and interacting with people in their natural settings. Observers are able to fully understand what life is like for the people they observe. In some instances, researchers will participate in the day-to-day activities of the people under observation to gain a better understanding of their needs. Most field researchers participate to some extent, but there are also times when they need to strictly observe.

Field research is well equipped to answer the question of “how” an event occurs. This is different from the “why” questions that surveys typically answer. When working in the field, you are asking *how* the processes you are evaluating occur, *how* people are spending their time, and *how* events unfold. Revisiting our cooling system example, you may understand *why* employees are reporting that the cooling system doesn’t work – because the lighting is too hot – but you may not understand *how* that problem affects them.

The Assessment Process

The goal of any ergonomics assessment is ensuring that people are placed in an environment where their physical, psychological, and social well-being is not affected by the building system. Successful assessments have been shown to increase motivation and personal growth, helping to improve performance. It is important to be attentive to an individual's social resources as well as their economic sustainability.

Initial Assessment

Reduced performance and compromised comfort levels can occur when there is a lack of human capability and aspiration. People may perform below their capabilities and standards because other parts of the system become obstacle rather than a supporting environment. During the initial assessment, you are seeking to create a framework for understanding four main components:

1. The environment that you are evaluating, often a building
2. The systems in place, e.g. heating, cooling, lighting, fenestration, insulation, etc.
3. The people within that space that interact with its systems
4. The opportunity cost associated with that project – what opportunities are you giving up in order to pursue this project?

Changes to any of these components can result in substantial changes to the system as a whole.

Understanding an environment

The space or environment is the high-level system within which all systems and people work or operate. In the case of an energy efficiency upgrade, your environment could be a commercial building, a home, a walkway, or a parking garage. In each example, the environment is very different. Even if you have the same types of systems and the same types of people in each of these spaces, changing the environment changes the system. Some things you may want to document about the environment are:

1. The size of the space as a whole
2. Areas of the environment that are functionally distinct
3. Spaces that you expect will be affected by a change to a system

Evaluating changes to systems

For efficiency upgrades, changes to building systems typically means replacing or modifying components that are in place for occupant comfort. It is not sufficient to determine an upgrade's success or failure based strictly on the energy savings that it provides. Changes in comfort levels for occupants are equally important to evaluate.

When evaluating an upgrade or modification, make a list of all the systems present in the environment. Then consider the impact your project may have on each of the systems. Often times, like in the cooling example discussed previously, there are important interactions between these systems that are not always obvious. This provides an opportunity to use interviews or surveys to identify interactions that you may not be aware of. Other questions to ask might be:

1. How much am I decreasing comfort to further increase efficiency?
2. Does this change impact everyone, or are some people more heavily impacted?
3. Can changes be made to the system to make it fit the people in the environment?
4. Can personal accommodations be made that prevent occupant discomfort?

Impacting people

During your initial assessment period, the most critical step is evaluating and accounting for as many personal impacts as possible. Ideally, the project will result in a more efficient system that leaves occupant comfort unchanged or improved. Achieving this requires a thorough evaluation of user requirements, tasks, and personal needs. Ensure that you have an understanding of how tasks are carried out and the environment in which they are performed. This may involve the tools outlined, especially those that focus on gathering occupant feedback. Field research is commonly used during this stage of evaluation. Plan to revisit and revise your assessment during the installation process.

It is important to note that the people in a space are typically part of an organization, whether it is an employer, family, or other group. The organization itself merits review as a part of this process. Policies and organizational structures often need revision as a result of a change to a building system. For example, if employees typically work late, a lighting system set to shut off at 5 p.m. will cause frustrations.

Installation Assessment

During the installation of a building system there will be an impact on the people occupying that space. While this impact is temporary, the best practice is to do whatever possible to minimize discomfort. If nothing can be done, then clear communication with occupants can help reduce frustration.

1. Document the expected duration of the installation and make sure that people are aware of what will be happening.
2. Discuss the changes with occupants to determine if temporary accommodations need to be made.
3. Revisit your initial assessment, checking for changes based on these discussions.

Post-installation Evaluation

Initial Evaluation

In the first weeks or months after the project, it is important to evaluate the impacts of the change. Questions to ask include:

1. Was the installation successful?
2. Are there any outstanding problems that need follow-up attention?

3. Does the installation perform as intended?

For each of these questions, collect user feedback and implement adjustments where possible. Gaining a small amount of efficiency should not outweigh significant impacts on the people working or living in that environment.

If there are problems that cannot be addressed, talk with the affected persons to create an action plan to make them more comfortable. This may involve changes to that person's activities or organizational changes to minimize the problem. If the new system requires additional training, talk with the occupants to find a time that is the least impactful on their day-to-day activities. Document any challenges or lessons learned for future projects.

Long-term verification

Establish a time in the future to re-evaluate, monitor and adjust the changed systems. During this time period, measure and evaluate the effectiveness of the system in achieving stated objectives and in maintaining user comfort. Some of the questions you may ask are:

1. Does the project still function properly?
2. Are occupants affected in new ways?
3. Have accommodations for impacted people been successful?
4. Are users happy with the project?

If there are new impacts, or if previous attempts to minimize human impacts were unsuccessful, design an action plan to address these needs. Refer to the "lessons learned" documentation that you collected during the initial assessment and be careful not to introduce new problems.

Users will be initially frustrated by changes to systems or organizational policy, but they will adjust over time. This is true for system changes requiring behavioral changes such as automated lighting or fenestration systems. Document these changes and determine if there has been any improvement in attitudes or acceptance since the installation. If additional training is needed, create an action plan to provide it in a timely manner. Schedule time to follow-up again after performing this evaluation.

Common Ergonomic Assessment Pitfalls

Scheduling and conducting the interviews takes time, sometime making this method very costly. Training interviewers may be necessary, including ensuring that the interviewer has enough knowledge of the subject matter and feels confident in his or her ability to conduct the interview. In addition, interviewer error or bias is a major problem. Changes in tone of voice or the phrasing of questions, or even the gender or appearance of the interviewer, can lead to errors and bias. Detailed interviews produce a huge amount of data in a short period of time, which can make analysis difficult. Too much flexibility can result in inconsistencies across interviews.

While surveys have a number of advantages, they also can create problems. Surveys are relatively inflexible tools. For example, if you mail out a survey to 500 employees and discover, as responses start coming in, that the phrasing in a question is confusing to respondents. It is too late to revise the question. In-depth interviews allow a researcher to provide additional clarification or explanation of a question.

Surveys also do a poor job of uncovering trends or results that you didn't expect. If your survey is looking to evaluate whether or not a cooling system is working properly, you might ask questions specific to that system. But what if employees are uncomfortable because the incandescent lamps at their workstation create too much heat? Respondents may feel that the cooling system is just fine and report that, while they are suffering from a problem that your survey could not uncover. Conversely, they may report that the cooling system is ineffective when the problem is the lighting system.

Field research is well equipped to answer the question of "how" an event occurs. This is different from the "why" questions that surveys typically answer. When working in the field, you are asking *how* the processes you are evaluating occur, *how* people are spending their time, and *how* events unfold. Revisiting our cooling system example, you may understand *why* employees are reporting that the cooling system doesn't work – because the lighting is too hot – but you may not understand *how* that problem affects them.

Field research is the most costly in terms of time and money because it takes the researcher a long time to gather the information. Costs may cause the collected data to come from a relatively small sample of the relevant population, skewing results.

Resources

Human Factors and Ergonomics Society: HFES.org

World Health Organization: Who.int

Clinical Human Factors Group: Chfg.org

A Strategy for Human Factors/Ergonomics: Developing the Discipline and Profession: http://www.tandfonline.com/doi/pdf/10.1080/00140139.2012.661087

Sociological Inquiry Principles: Qualitative and Quantitative Methods: http://2012books.lardbucket.org/books/sociological-inquiry-principles-qualitative-and-quantitative-methods/index.html

Appendix A-2: References and Standards

American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. ASHRAE Guideline 0-2005. "The Commissioning Process". March 2005.

American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. ASHRAE Guideline 14-2002. "Measurement of Energy and Demand Savings". June 2002.

American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. ASHRAE. "Measurement of Energy and Demand Savings: How to determine what was Really Saved by the Retrofit". October 2005.

American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. ASHRAE Journal. "Commissioning Design/Build Projects". October 2012.

Efficiency Valuation Organization. "International Performance Measurement and Verification Protocol: Concepts and Options for Determining Energy and Water Savings Volume 1." January 2012.

Pacific Northwest National Laboratory. U.S. Department of Energy. "Standard Measurement and Verification Plan for Lighting Retrofit Projects for Buildings and Building Sites." October 2012.

The Cadmus Group, Inc. "California Statewide Codes and Standards Program." February 2012.

APPENDIX B:
Residential LED Luminaires and Lamp Replacements

Appendix B: RLLR Assessment Report

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EXECUTIVE SUMMARY

Introduction

In California, about 90 percent of installed residential luminaires are considered low-efficacy under the 2013 Building Energy Efficiency Standards (Title 24, Part 6). Low efficacy lighting includes all forms of incandescent and some types of fluorescent lighting. At the national level, approximately 65 percent of homes still use incandescent sources. Less than one percent utilize light-emitting diode (LED) replacement lamps and dedicated LED luminaires.

In 2012, the California Energy Commission (Energy Commission) published a Voluntary California Quality Light-Emitting Diode Lamp Specification to set a minimum specification for certain types of LED lamps intended for use in California. This specification is not mandatory, but adoption is encouraged in an effort to increase energy savings and lighting quality for all Californians. The California Public Utility Commission (CPUC) has adopted this standard as the minimum performance specification for lamps receiving an incentive/rebate from a California investor-owned utility (IOU).

Project Purpose

The goal of this project is to demonstrate and evaluate the performance and cost effectiveness of commercial-off-the-shelf (COTS) LED luminaires and LED pin and screw-base lamp replacements in a residential setting. LED products are poised to replace fluorescent and incandescent sources for nearly all residential applications, and this research is intended to inform stakeholders on in-situ performance and consumer perceptions of the technology.

Project Approach

For this demonstration, staff considered LED replacement lamps meeting California's 2013 residential energy efficiency standards. In addition, cost-effective products providing adequate light output for residential applications and meeting the Voluntary California Quality Light-Emitting Diode Lamp Specification were prioritized during the selection process.

Staff selected a multifamily, residential apartment complex for demonstration of selected products. The demonstration site consisted of 24 individual apartment units, each approximately 600 square feet in area. Staff completed site audits to identify the existing lighting systems and lighting needs. Using this information, the team designed and installed replacement LED solutions for the majority of living spaces within each apartment. Demonstrated products included medium, screw-base LED lamps (A lamps), tubular LED lamps (TLEDs) and GU-24 LED lamps.

In parallel with this work, staff designed and deployed pre and post-retrofit occupancy surveys and collected lighting energy and time-of-use data to estimate annual energy use and savings resulting from the project.

Project Results

Based on national residential lighting use studies, it is estimated that by replacing traditional light sources in a typical US residence homeowners can expect a simple payback of 3.2 years. Over a 15-year period, the incremental net present value of this project is estimated to be $1,084. While demonstrated energy savings are significant as compared to baseline systems, results in a multifamily scenario are cost-effective only under certain conditions. Homes where the existing annual lighting use intensity (kWh per square foot) is greater than approximately 0.25 results in a simple project payback of less than

15 years. Fifteen years represents a typical lighting project evaluation period. The site-specific combination of product costs and low lighting use levels result in an average project payback period of 14.7 years. Homeowners considering the switch from incandescent or CFL screw-base lamps only, based on outcomes of this demonstration and other published data, may expect a payback of 2-4 years. In addition, lighting utilization data also shows the space types in the home where lighting is used more frequently: the kitchen, living room and dining room. Focusing retrofits in these areas of the home will result in a more cost-effective lighting retrofit for the typical apartment resident.

Technology Development

Four-foot LED lamp replacement solutions that adhered to the residential lamp requirements of the project available for purchase at the time of this demonstration were minimal. In addition, the manufacturer of the selected product issued a recall for this lamp citing: Electrical arcing may cause the lamp to overheat and melt, posing a burn hazard. Development of cost-effective, safe, four-foot LED replacement lamps that meet the California energy efficiency standards is recommended to increase market adoption of residential LED lamps. In addition, at the time of this demonstration, there were limited commercialized products available that met the project criteria for GU-24 sockets. Additional development of cost-effective GU-24 LED replacement lamps compliant with California energy efficiency standards is recommended to address the GU-24 sockets unique to California homes.

End User Acceptance

Apart from technology availability and associated costs issues, LED replacement solutions were very well received by occupants participating in the project. When asked to identify the issue most bothersome to them about the new lighting system, 94 percent of respondents responded ‘nothing’.

Staff collected additional survey data to understand residential use patterns and identify areas most in need of lighting retrofits. Occupants were asked to rank the criteria that is most important to them when purchasing lighting products: lifetime, price, lighting color, light distribution, brightness, energy efficiency, lower energy bills and other. The top criteria selected was lifetime followed by lower energy bills suggesting that the long-life LED products were well-suited to residents’ needs.

When asked which area of the apartment received the largest lighting improvement due to the lighting retrofit, 75 percent of respondents replied the kitchen. The lighting utilization data indicates that the kitchen is also the space most used by occupants. Products developed specifically for high traffic areas of the home such as the kitchen are expected to be well-received and improve market adoption of LED technology.

CHAPTER 1: Introduction

Residential applications in the United States are equipped with a cross-section of light source types, each with varying energy efficiencies. As of 2010, there were a total of 113,153,000 residences in the United States.[1] In these residences, 62 percent of lamps were incandescent, 23 percent were compact fluorescents (CFLs), 10 percent were linear fluorescent, 4 percent were halogen, and less than one percent were other luminaire types including light-emitting diode (LED) replacement lamps and dedicated LED luminaires.[2]

In California, about 90 percent of installed residential luminaires are considered low-efficacy under the 2013 Building Energy Efficiency Standards (Title 24, Part 6). Low efficacy lighting includes all forms of incandescent and some types of fluorescent lighting. At the national level, approximately 65 percent of homes still use incandescent sources. Less than one percent utilize light-emitting diode (LED) replacement lamps and dedicated LED luminaires.

In 2012, the California Energy Commission (Energy Commission) published a Voluntary California Quality Light-Emitting Diode Lamp Specification to set a minimum specification for certain types of LED lamps intended for use in California. This specification is not mandatory, but adoption is encouraged in an effort to increase energy savings and lighting quality for all Californians. The California Public Utility Commission (CPUC) has adopted this standard as the minimum performance specification for lamps receiving an incentive/rebate from a California investor-owned utility (IOU).

The goal of this project is to demonstrate and evaluate system performance and cost effectiveness of dedicated LED luminaires and lamp replacements for residential applications specifically located in California where aggressive energy efficiency standards have been in effect for 40 years. Technology demonstrations included the market analysis, potential economic impact analysis, technology selection, assessment plan development, technology installation and pre and post retrofit data collection.

[1] US DOE 2010 U.S. Lighting Market Characterization, pg. 37, table 4.10

[2] US DOE 2010 U.S. Lighting Market Characterization, pg. 39, table 4.12

CHAPTER 2:
Market Assessment

The Commission estimates its energy efficiency standards have saved Californians over $74 billion in electricity costs since they were first adopted in 1975. For homeowners, energy efficiency helps ensure that a home is affordable to operate both now and in the future. California's efficiency standards increase the reliability and availability of electricity, thus allowing the electrical system to operate in a more stable manner. This benefits California's economy as well as the health and well-being of all Californians.[3]

The 2013 Building Energy Efficiency Standards, effective July 1, 2014, place a strong emphasis on high-efficacy lighting, lighting controls, and high performance fenestration products. In addition to increasing requirements for high-efficacy lighting in the home, the 2013 Title 24 standards set a minimum quality standard for LED luminaires. These quality standards can be found in the Joint Appendices (JA) Section 8.[4] LED luminaires must have a minimum color rendering index (CRI) of 90 to qualify as high efficacy. Indoor LED luminaires must have a correlated color temperature (CCT) between 2,700 K and 4,000 K.

Market Analysis

As of 2010, there were a total of 113,153,000 residences in the United States.[5] In these residences, 62 percent of lamps were incandescent, 23 percent were CFLs, 10 percent were linear fluorescent, 4 percent were halogen, and less than 1 percent was other luminaire types, including LED replacement lamps and integrated LED luminaires.[6] About 90-95 percent of these luminaires are considered low-efficacy under 2013 Title 24.

These homes used an average of 46 watts per lamp[7] and had about 51 lamps per residence[8]; only three lamps per home incorporated dimming controls.[9] This lighting operated for an average of 1.8 hours per day, which is equal to 1,556 kWh of electricity use per year. Lighting power density ranged between 1.0 and 1.4 watts per square foot (W/sf) of interior space.[10] As of 2010, there were still a very high number

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[3] California's Energy Efficiency Standards Have saved $74 Billion, California Energy Commission, 2015.

[4] 2013 Building Energy Efficiency Standards, 2014.

[5] US DOE 2010 U.S. Lighting Market Characterization, pg. 37, table 4.10

[6] US DOE 2010 U.S. Lighting Market Characterization, pg. 39, table 4.12

[7] US DOE 2010 U.S. Lighting Market Characterization, pg. 40, table 4.13

[8] US DOE 2010 U.S. Lighting Market Characterization, pg. 42, table 4.15

[9] US DOE Residential Lighting End-Use Consumption Study, pg. 4.8, table 4.6

[10] US DOE 2010 U.S. Lighting Market Characterization, pg. 42, table 4.15

of incandescent lamps in use, and most CFL lamps are equipped with screw bases and are considered low-efficacy by Title 24.

Current estimates expect a 1.22 percent annual growth rate in residential building stock[11] LEDs are expected to expand their market presence, representing 25 percent of the installed base of lumen-hours by 2020 and 62 percent by 2030.[12]

Table 1. US Residential Lighting Use by Socket Type (%)

Room Type	Electricity use per room (kWh/yr.)	Incandescent	CFL	Linear Fluorescent	Halogen	Other	Total Sockets per Home (%)[13]
Bathroom	242	74%	20%	3%	2%	1%	18%
Living/Family Room	228	61%	29%	3%	5%	1%	14%
Bedroom	222	67%	28%	2%	3%	0%	16%
Kitchen	215	45%	23%	22%	7%	3%	13%
Exterior	214	59%	24%	2%	14%	2%	11%
Hall	111	72%	22%	2%	4%	1%	8%
Dining Room	105	81%	15%	1%	3%	0%	6%
Garage	69	35%	13%	51%	1%	0%	5%
Office	41	58%	27%	8%	6%	0%	4%
Closet	32	60%	20%	17%	2%	0%	N/A
Basement	28	40%	30%	28%	1%	0%	N/A
Other/Unknown	26	53%	17%	24%	6%	0%	5%
Laundry/Utility Room	25	50%	19%	28%	2%	0%	N/A

[11] Navigant Consulting Energy Savings Potential of Solid State Lighting in General Illumination Applications, pg. 6

[12] US DOE Energy Savings Potential of Solid State Lighting in General Illumination Applications, pg. 39

[13] Energy Star CFL Market Profile, Page 23, Table 11

Economic Analysis

Using statistics for the average single family residence, noted above, staff completed an economic analysis for a complete residential remodel scenario. The analysis describes a typical LED retrofit based on current material costs, estimated material useful life, installation costs and typical residential maintenance practices.

To determine the average wattage of LED replacement lamps that meet Title 24 requirements and adhere to the Voluntary California Quality Light-Emitting Diode Lamp Specification, staff referenced the LED Performance Database. At the time of this analysis, eight lamps were reported at 90 CRI or greater when tested by a third-party laboratory. The average wattage of these eight lamps was 11.2 Watts.

The sample of Title 24-compliant lamps ranged in price from $6.47 to $18.80, including rebates provided by local utilities. The average Title 24-compliant LED lamp cost $11.90 as of the time of the analysis.

The typical LED replacement lamp is rated for 25,000 hours of operation. Using the assumed 1.8 hours per day operation, the estimated useful life of an LED replacement lamp in a residential application is 38 years. Installation costs and typical residential maintenance practices are assumed negligible for lamp replacements and not included in the estimated economic analysis calculation.

There is an estimated load reduction of 76% assuming the baseline lighting of 46 Watts per lamp is upgraded with LED replacement lamps with an average wattage of 11.2. Based on typical residential lighting use, the calculated annual, LED lighting energy use is estimated to be 378 kWh.

Based on Electric Schedule E-1 for Residential Services, the total baseline usage rate is $0.16352/kWh.[14] This rate is used in 15-year lifecycle cost analysis estimate with the estimated energy savings, average material cost and estimated useful life. An assumed inflation rate of 4 percent is used to evaluate the project over time. By replacing traditional light sources in a typical residence, homeowners can expect a simple payback of 3.2 years for an LED retrofit. Over a 15-year period, the incremental net present value of this project is estimated at $1,084.

[14] PG&E. Electrical Schedule E-1 for Residential Services. March 1, 2015.

CHAPTER 3: Technology Demonstration

For this demonstration, staff considered LED replacement lamps meeting California's 2013 residential energy efficiency standards. In addition, cost-effective products providing adequate light output for residential applications and meeting the Voluntary California Quality Light-Emitting Diode Lamp Specification were prioritized during the selection process.

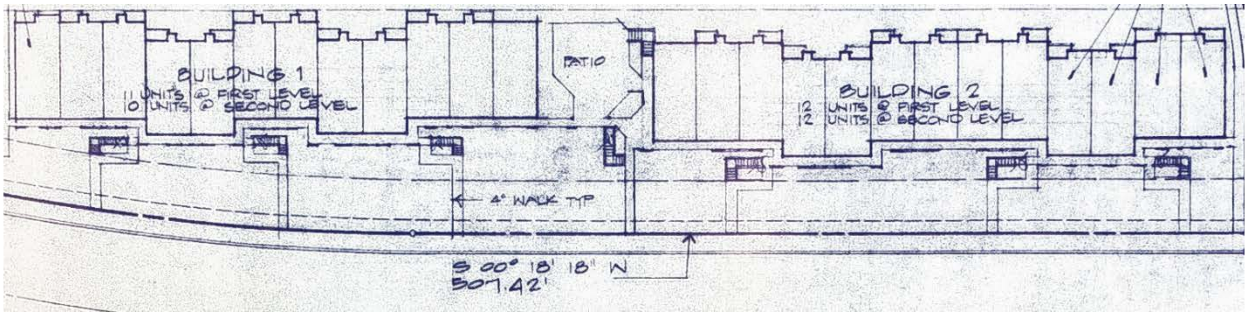
Demonstration Site

The selected demonstration site is a multi-tenant residential retirement community located in Northern California (Climate Zone 12). The apartment complex has 45 single resident, single-bedroom apartments; 24 of the apartments participated in the demonstration. The apartments are in two two-story buildings, as seen in Figure 2. The unit entrances are oriented west and are shaded by trees in the afternoon. Each apartment is approximately 600 square feet (sf) in area.

Figure 1. Apartment Complex – demonstration site

Source: CLTC

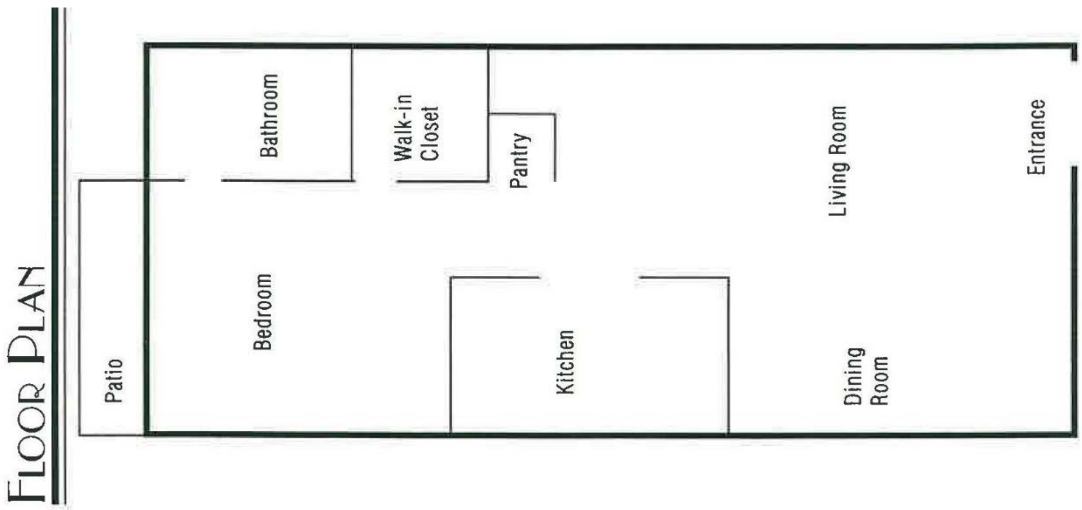
Figure 2. Demonstration site – site plan



Source: Cottonwood Meadows Apartments

Each apartment includes a living/dining room, kitchen, bedroom, closet and bathroom, shown in Figure 3. Windows are located in the living/dining area and in the bathroom. The bedroom includes a sliding glass door.

Figure 3. Apartment Floor Plan



Source: Cottonwood Meadows Apartments

Each apartment was equipped with dedicated (hard-wired) luminaires in the bathroom, closet, hallway, dining room and kitchen. Site audits revealed an average of four tenant-owned portable luminaires per apartment. All portable luminaires were equipped with medium incandescent or CFL screw-base lamps. The pre-retrofit lighting schedule, excluding portables, is provided in Table 2. Portable luminaire lamp and fixture types varied among the apartments. Five apartments at the demonstration site received a lighting upgrade in 2010. During this upgrade, two dome fixtures were replaced with globe fixtures using fluorescent circuline lamps.

Table 2. Pre-Retrofit Lighting Schedule

Room	Luminaire	Power (W)
Bathroom	2 lamp, 2 foot T12, Vanity Fixture	66
Walk-in closet	1 lamp, medium base, Downlight	40
Hall (near kitchen)	1 lamp, medium base, Dome Fixture	60-120
Dining Room	1 lamp, medium base, Dome Fixture	60-120
Kitchen	4 lamp, 4 foot T12, Wrap Fixture	144
Kitchen	1 lamp, medium base, Dome Fixture	60-120

All luminaires were manually switched. No building management systems or other controls were used for individual tenant lighting. Photos of representative lighting conditions in the living room, kitchen and bathrooms are provided in Figure 4 and Figure 5. Lighting maintenance was performed on a case-by-case basis when residents notified the complex office of an outage or issue.

Figure 4. Pre-Retrofit Lighting Conditions - Living Room

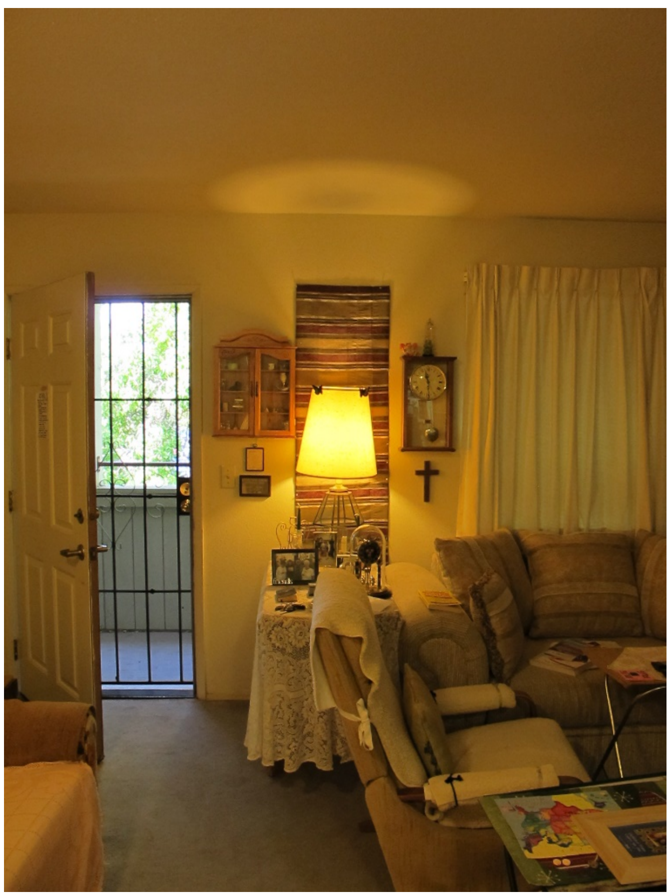


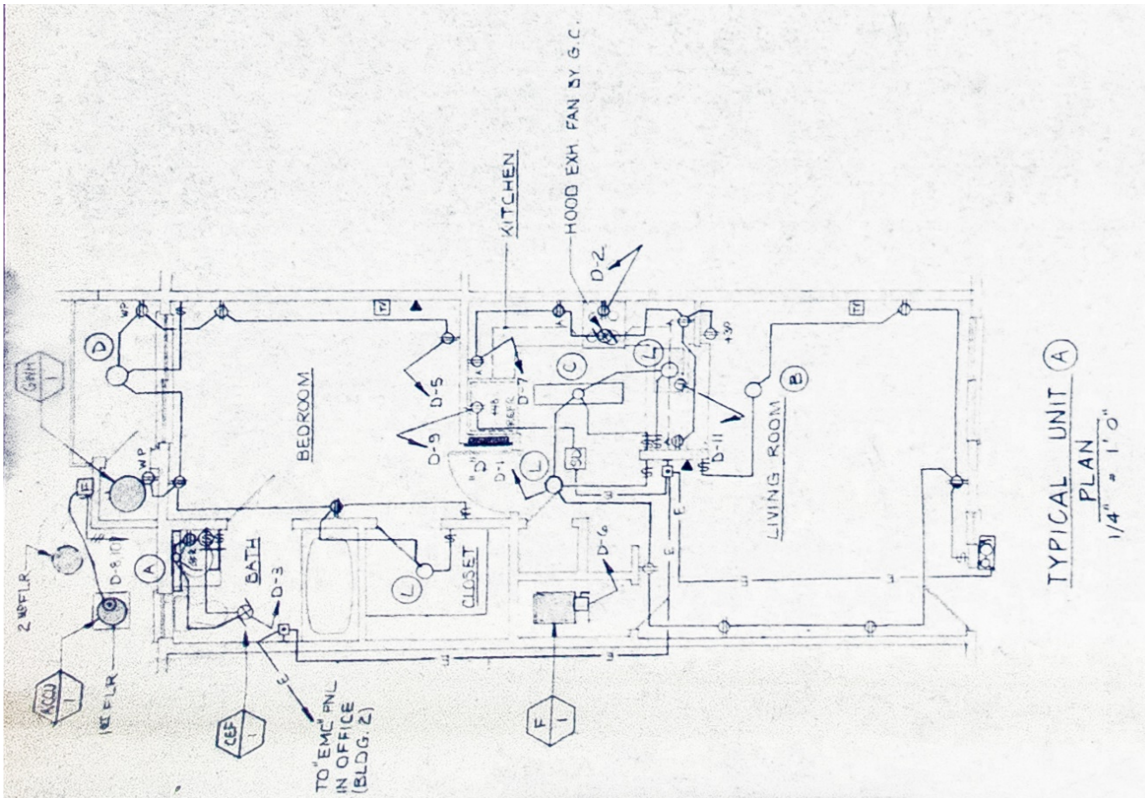
Photo Credit: CLTC

Figure 5: Pre-Retrofit Lighting Conditions – Kitchen and Bathroom

Photo Credit: CLTC

Staff identified lighting and plug load circuits from electrical diagrams provided by the site. These circuits, bathroom (D-3), bedroom/closet (D-5) and kitchen/ living room (D-1), are shown in Figure 6. Site inspection confirmed that the permanent lighting and receptacles were split between two circuits. The first 15-amp circuit, labeled Circuit 3, contained the kitchen and living room luminaires and general purpose receptacles. The second 15-amp circuit, labeled Circuit 4, provided power for the lighting and general purpose receptacles in the bedroom, closet and bathroom.

Figure 6. Apartment Electrical Plan



Source: Cottonwood Meadows Apartments

Product Selection

Staff utilized the Design Lighting Consortium's (DLC) Qualified Product List (QPL) to identify lighting products that met project criteria. Staff reviewed all listed four-foot tubular LED products in the DLC-QPL at the time of the product evaluation. More than 200 listed products were considered. Data on CRI and lamp efficacy for all reviewed products is provided in Figure 8. The project team filtered this data to include lamps with CCT ranging from 2,700-3,500 K. This CCT range is typical and appropriate for most residential spaces. At the time of the review, there was one product on the DLC-QPL that met project requirements, a Linear LED T8 Series product with a manufacturer efficacy rating of 105 lumens/Watt (lm/W).[15]

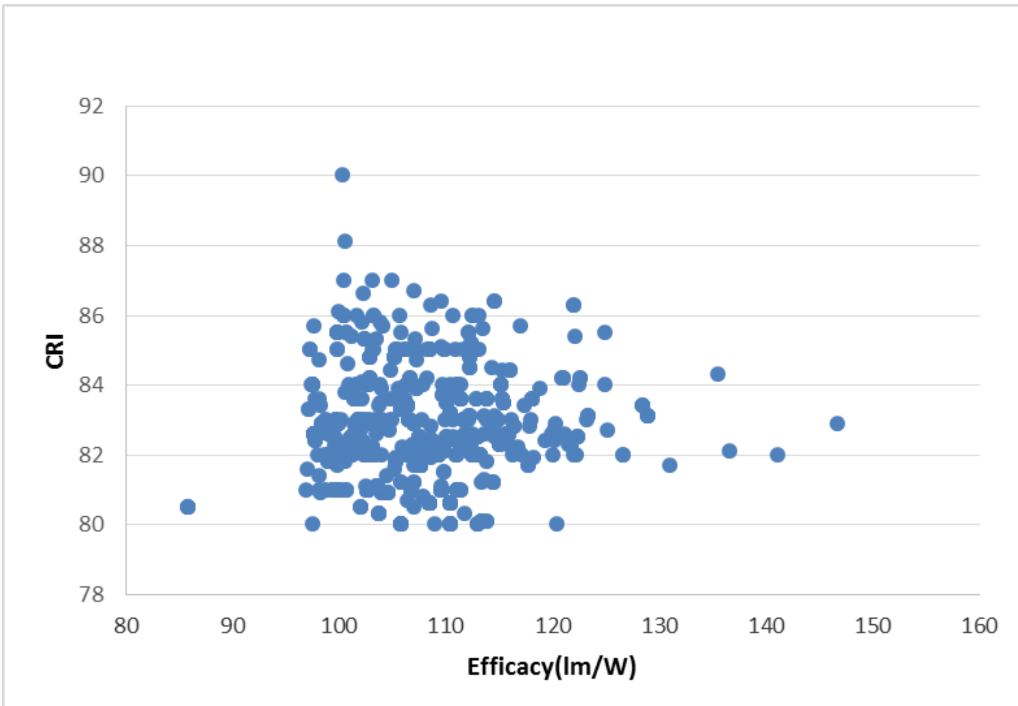
For screw-base (A-lamp) LED replacements, staff used the [LED Performance Database] to identify suitable products. At the time of the evaluation, there were five products in the database that met project requirements, shown in Figure 7. Staff prioritized color rendering capability and lamp efficacy

[15] On June 4, 2015, the manufacturer issued a recall for this lamp citing: Electrical arcing may cause the lamp to overheat and melt, posing a burn hazard. https://www.cpsc.gov/en/Recalls/2015/Cree-Recalls-LED-Lamps/

when selecting demonstration products. Staff selected a High CRI 60 Watt equivalent replacement lamp with an efficacy of 84 lm/W and price of $6.66.

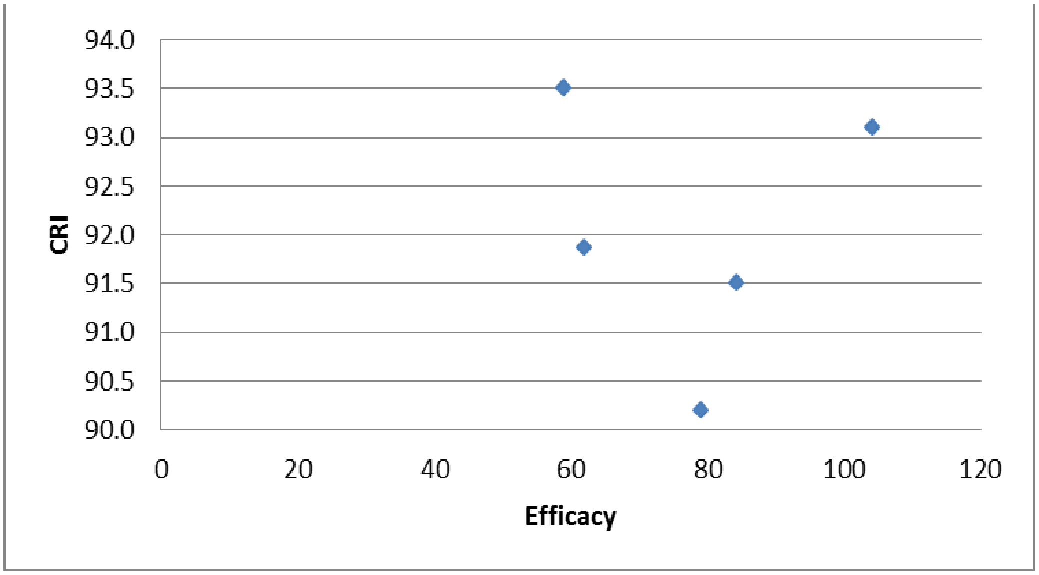
Staff also reviewed GU-24 fixtures and LED lamps to update the existing T12 fixture present in some apartment bathrooms. GU-24 lamps that met all project criteria were limited. The Illumis GU-24 base lamps were selected along with a new vanity fixture to replace the two-foot T12 linear fluorescent fixture.

Figure 7. Four-Foot Tubular LED Products from the DLC Qualified Product List



Source: CLTC

Figure 8. Medium Base 60 Watt Equivalent LED Replacement Lamps



Source: CLTC

Lighting Design

To finalize the retrofit lighting system design, the project team completed laboratory lamp testing to verify manufacturer's performance claims of the selected products when installed in light fixtures found at the demonstration site.

Staff completed photometric modeling (AGi32 software) using third-party data to determine projected (post-retrofit) light levels in the bathroom and kitchen as compared to the IES recommended practices. Recommended practice for critical applications in residences with a target age of the typical resident being greater than 65 years old is provided in Table 3.

Table 3: Lighting for Residences per IES Handbook, 10th Edition and Modeled Lighting Levels

Application and Task	Horizontal Illuminance Target (Avg. fc)	Modeled Horizontal Illuminance (Avg. fc)	Notes
Kitchen			
General	10	50	E_h @ floor; E_v @ 4'AFF
Cooktops	60	42	E_h @ cooking surfaces
Preparation Counters	100	42	E_h @ prep surfaces
Bathroom			
Toilet	20	6	E_h @18"
Vanity (Grooming)	40	10	E_h @ 3'; E_v @ 5'AFF

Figure 9. Modeling Results - Retrofit Lighting System – Bathroom

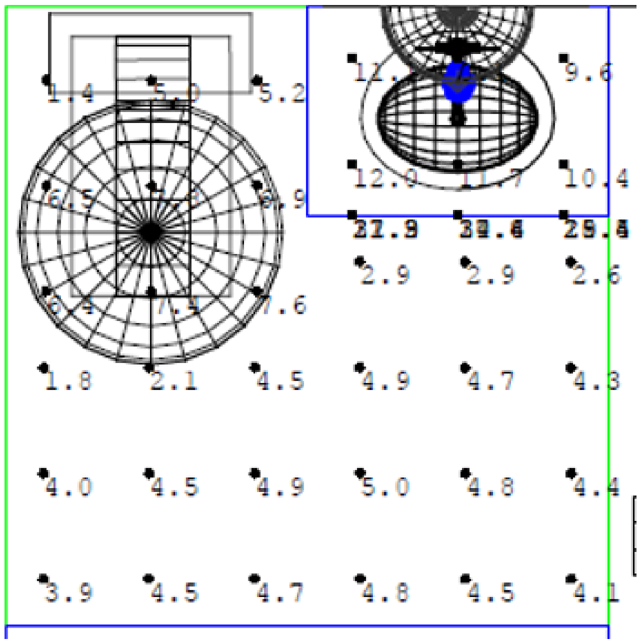
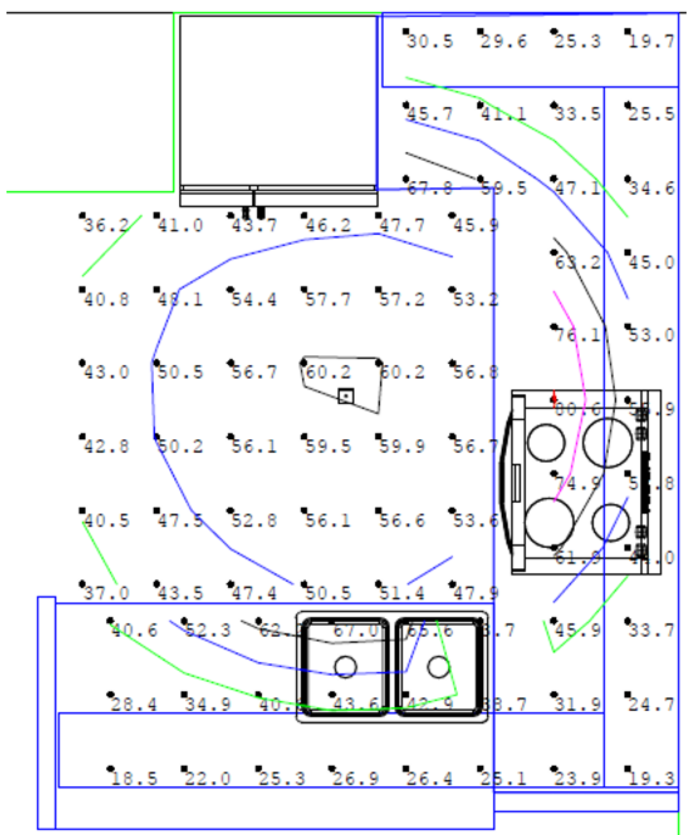


Figure 10. Modeling Results - Retrofit Lighting System - Kitchen



Source: CLTC

Retrofit Lighting Schedule

The retrofit lighting schedule is provided in Table 3. Full specifications for each product are provided in Appendix A.

Table 4. Retrofit Lighting Schedule

Room	Retrofit Lighting System	Power per Unit (W)
Bathroom	GU-24 High CRI Lamp, new Vanity Fixture	13.7
Walk-in closet	High CRI Lamp, Downlight Fixture	9.5
Hall (near kitchen)	High CRI Lamp, Dome Fixture	9.5
Dining Room	High CRI Lamp, Dome Fixture	9.5
Kitchen	Linear LED T8 Series	21
Kitchen	High CRI Lamp, Dome Fixture	9.5

Table 5: Schedule of Screw-Base Lamps by Apartment

Apt.	No. of Screw-Base Lamps
1	6
5	6
22	4
24	6
26	5
29	6
44	6
4	8
15	3
17	7
21	4
27	4
28	8
30	6
31	6
32	4
33	8
36	4
37	7
39	7
42	8
43	5

CHAPTER 4:

Measurement and Verification Plan

Staff prepared a measurement and verification that details the procedure, equipment and analysis methods used to gather lighting energy use, lighting utilization, and occupant feedback from each of the participating apartment homes.

- *Lighting energy use* data is used to evaluate the energy savings and cost effectiveness of the LED luminaires and lamp replacements as compared to typical residential lighting systems including the existing lighting systems at the demonstration site.
- *Lighting utilization* data is used to identify key areas in residential applications where lighting fixtures are most frequently used by occupants.
- *Occupant surveys* are used to capture end user feedback regarding the environment, pre-retrofit lighting system, post-retrofit lighting system and system user demographic information.

Participating apartments were divided into 'retrofit' and 'control' groups. Of the 24 participating apartments, 17 were retrofitted with LED products, and seven were used as control apartments. Each of the retrofit and control apartments were equipped with lighting energy use and lighting utilization monitoring equipment, which are described in the following sections. Each participating apartment completed a pre- and post-retrofit survey.

Lighting Energy Use

The baseline monitoring period spanned two weeks, from January 5, 2015 to January 18, 2015. This duration is sufficient to determine a typical weekly operating schedule and load profile for the baseline lighting system. The post-retrofit monitoring period spanned seven weeks, from January 27, 2015 through March 15, 2015. Data analysis was conducted to determine the average, daily, lighting energy use of each apartment and extrapolate the estimated annual lighting energy use and savings compared to the baseline system. Collected data is provided in the Appendix F.

The two 15-amp lighting/receptacle circuits were monitored for energy use using a HOBO Data Logger, WattNode Revenue Pulse sub-meter and Revenue Grade 20-amp current transducer (CT). To isolate the lighting loads from the plug loads, ThinkEco Modlet plug load loggers were installed on all receptacles in each participating apartment. The use of the plug load loggers allowed the project team to isolate the lighting energy use by subtracting the monitored energy use of non-lighting plug loads from the circuit-level HOBO energy use data. Full specifications of the measurement and verification equipment is provided in Appendix B.

The WattNode Revenue Pulse sub-meter measures energy use via revenue grade current transducers (CT) and voltage inputs. Measurements are converted into pulses by the WattNode. The pulses were recorded by the HOBO energy logger. Using the software from HOBO, the HOBO state logger was to reset and programmed with a sampling rate of one minute. The meter, CT and data logger were wired according manufacturer recommendations.

Figure 11. WattNode Revenue Grade Meter (left); Revenue Grade Current Transducer (right); HOBO Energy Logger (Bottom)

The ThinkEco Modlet is a plug load power monitoring device shown in Figure 14. The ThinkEco Modlet plugs into a power outlet allowing it to power and monitor plug load devices. The ThinkEco Modlet communicates wirelessly a cloud service to transfer energy use data. The ThinkEco Modlet is capable of storing up to 12 days of data during network outages. Using the recommended cabling, the ThinkEco Modlet was reset and programmed to record at a sampling rate of 15 minutes. One ThinkEco Modlet was installed at each receptacle per site.

Figure 12. ThinkEco Modlet Receptacle Measurement Device

Source: ThinkEco

To calculate lighting energy saved by the retrofit, Equation 1 was used where net lighting energy saved is equal to the post-retrofit energy consumption subtracted from the baseline system energy consumption using post-retrofit hours of use. This calculation is performed using the average, daily, post-retrofit lighting energy hours-of-use for each apartment and the baseline and retrofit lighting systems load.

Equation 1: Net Energy Savings

$$NES = BEUa - PEU$$

Where, NES = Net energy savings

BEUa = Baseline energy use (adjusted)

PEU = Post-retrofit energy use

Lighting Utilization

Lighting utilization data is used to identify key residential areas where lighting fixtures are most frequently used by occupants. To gather lighting utilization data, the project team deployed HOBO Pendant Light Loggers to record light levels for all light fixtures in each apartment. These loggers record the percentage of time ON for each light source per apartment.

Light loggers collected discrete illuminance values with a sample rate of one minute. Each was installed securely within or near the luminaire with the photocell facing the unobstructed light source. Device memory accommodates up to 28,000 measurements. Full specifications for this device is provided in Appendix B.

Figure 13. HOBO Pendant Temperature and Light Logger

Source: Onset

To differentiate between the light output of the fixture and daylight/other electrical light source contributions, illuminance measurements greater than 25 percent of the maximum recorded illuminance value taken when the light was OFF were defined as periods of time when the light source was ON. The percentage of time spent ON versus total time monitored was calculated for the benchmark and post-retrofit lighting systems.

Cost Effectiveness

Lifecycle cost analyses (LCA) were performed to determine the simple payback, incremental net present value (NPV) and internal rate of return (IRR) of the demonstration retrofit for each apartment monitored. The LCA is based on the installation labor and material costs incurred during the project. Cost analysis is also provided for lamp replacements only, excluding the cost of fixture upgrades needed to demonstrate the lamp technology.

The incremental NPV is provided to determine if the retrofit lighting technology will have a positive or negative cash flow for the 15 year lifecycle analyzed. IRR estimates the growth of investment options, with the highest IRR being most likely to return 'strong growth'.[16] To determine the IRR, an assumed finance rate of 8 percent and reinvestment rate of 3 percent are used. An assumed inflation rate of 4 percent is used for LCA calculations.

Analysis also includes a measure of simple payback. This is the initial investment divided by the annual savings experienced as a result of the investment, and is the number of years required to pay for the investment with the project savings. Results of all analyses are provided in the Project Outcomes section of this report.

Occupant Survey

To understand the environment, lighting system and the system user demographic, a survey tool was created and deployed to residents living in retrofit and control apartments. The survey was completed for pre- and post-retrofit apartments. A copy of the pre-retrofit and post-retrofit surveys are provided in Appendix C.

[16] Internal Rate of Return. www.investopedia.com. January 2015.

CHAPTER 5:

Project Outcomes

Baseline Performance

Apartments were monitored from December 18, 2014 to January 26, 2015 (40 days) to establish a baseline for residential lighting utilization based on the percentage of time lights were identified as ON for the monitoring period per space type. Table 5 provides benchmark residential space use per apartment. Space types reported as N/A did not have a light source available to monitor. Most apartments utilized kitchen and living room lighting the most. Full results are provided in Appendix F.

Table 6. Pre-Retrofit Lighting Utilization per Space Type

Apt	Bedroom	Bathroom	Closet	Dining	Hall	Kitchen Globe	Kitchen Wrap	Living Room
1	1.3%	1.2%	0.2%	10.0%	0.0%	0.4%	6.4%	27.9%
4	4.0%	0.5%	0.0%	7.8%	7.6%	3.0%	5.0%	6.8%
5	5.9%	4.2%	0.7%	0.1%	2.2%	4.3%	4.8%	43.7%
15	N/A	64.7%	0.5%	N/A	N/A	0.0%	53.1%	0.5%
17	N/A	2.1%	0.6%	4.5%	9.1%	40.9%	10.0%	23.5%
21	N/A	5.0%	3.4%	8.3%	26.2%	0.0%	6.4%	N/A
22	N/A	3.4%	0.1%	N/A	0.0%	35.2%	27.6%	0.4%
24	4.9%	16.4%	5.5%	19.0%	7.0%	7.5%	25.8%	11.6%
26	13.6%	8.7%	8.8%	3.5%	1.1%	11.7%	16.7%	N/A
27	8.8%	11.2%	2.8%	N/A	N/A	3.0%	5.8%	3.9%
28	23.0%	2.2%	0.1%	19.9%	0.0%	90.5%	6.5%	7.0%
29	2.7%	1.2%	0.3%	0.1%	0.2%	0.0%	9.8%	36.8%
30	1.4%	1.6%	0.6%	1.6%	0.3%	1.6%	12.0%	0.8%
31	N/A	1.2%	0.2%	5.1%	0.1%	0.5%	9.7%	31.5%
32	N/A	1.9%	1.0%	0.1%	0.1%	42.0%	2.0%	N/A
33	15.6%	0.8%	0.8%	0.0%	0.0%	0.0%	19.3%	40.5%
36	N/A	36.9%	3.5%	21.4%	2.0%	1.5%	0.3%	N/A
37	0.3%	1.7%	0.6%	23.4%	4.8%	3.4%	17.0%	26.4%
39	2.0%	3.5%	9.6%	6.5%	4.9%	11.2%	7.1%	15.4%
42	9.3%	7.9%	3.0%	0.3%	4.2%	0.1%	37.4%	20.0%
43	N/A	2.0%	0.19%	0.50%	N/A	0.17%	2.37%	47.93%
44	4.5%	4.8%	0.2%	0.6%	0.0%	0.0%	N/A	3.8%
Avg	**6.9%**	**8.3%**	**1.9%**	**7.0%**	**3.7%**	**11.7%**	**13.6%**	**19.4%**

Due to a large variance in the pre and post-retrofit hours of use across all apartments, pre-retrofit lighting energy use is reported as the pre-retrofit load using post-retrofit time-of-use hours. The pre-retrofit load varied by apartment. The range of loads, by apartment space type, is provided in Table 6. Estimated annual energy use, using these values, is provided in Table 7. The average, annual use was

274 kWh, which was much lower than the national average of 1556 kWh. National averages represent single family homes, while this demonstration site is a multifamily residential community. The number of installed lamps was also significantly lower than national averages. Published information on multifamily residential lighting use was not readily available for comparison.

Table 7. Pre-Retrofit Lighting Schedule

Room	Retrofit Lighting System	Power per Unit (W)
Bathroom	T12 single lamp - vanity fixture	40-60 W
Walk-in closet	Screw-base, single lamp - Downlight Fixture	13-60W
Hall (near kitchen)	Screw-base, single lamp - Dome Fixture	13-60W
Dining Room	High CRI Lamp, Dome Fixture	13-60W
Kitchen	T8, two lamp – Strip fixture	55-70W
Kitchen	Screw-base, single lamp - Dome Fixture	13-60W

Table 8. Calculated Annual Lighting Energy Use (kWh) with Pre-retrofit Lighting System

Apt	Bedroom	Bathroom	Closet	Dining	Hall	Kitchen Globe	Kitchen Wrap	Living Room	Total
4	6.31	0.00	0.70	113.53	16.29	2.10	21.44	0.00	160.38
15	N/A	0.00	1.40	14.72	12.09	0.00	55.50	4.20	87.92
17	N/A	14.45	4.20	13.67	6.31	47.30	122.36	35.74	244.04
21	N/A	50.88	7.36	31.01	12.61	93.56	5.05	N/A	200.46
27	6.83	36.42	1.05	18.92	4.73	68.33	75.69	1.58	213.55
28	76.74	13.88	4.20	80.94	12.61	47.83	102.18	69.38	407.76
30	9.46	5.78	2.10	1.58	0.00	32.59	10.09	0.53	62.13
31	N/A	0.00	0.35	1.05	N/A	0.00	203.09	67.80	272.30
32	8.41	6.94	3.50	0.00	0.00	141.39	3.78	0.53	164.55
33	17.34	83.26	0.70	0.00	0.53	0.00	512.14	162.94	776.91
36	N/A	26.02	14.37	0.00	9.99	13.14	17.66	N/A	81.17
37	17.87	39.89	2.45	187.11	28.91	2.63	200.57	1.05	480.49
39	34.69	10.99	18.57	14.72	6.83	44.15	84.52	76.74	291.20
42	22.60	44.52	13.67	9.99	15.77	2.10	194.26	52.03	354.94
43	N/A	18.50	1.05	0.53	12.61	0.00	0.00	63.60	96.29
AVG	**22.3**	**23.4**	**5.0**	**32.5**	**9.9**	**33.0**	**107.2**	**41.2**	**274.7**

Occupant Survey

Responses from the occupant pre-retrofit survey were collected from all 24 participating apartments. Full survey responses are provided in Appendix D. 25 percent of survey respondents were male, and 75 percent were female. A majority of participants fell between 55 and 64 years of age. Additional age details are provided in Table 9.

Table 9. Age of Survey Respondents

Age Group	Fraction of Respondents in each Age Group
35-44	4%
45-54	8%
55-64	46%
65-74	21%
75-84	21%
85 or more	0%

The level of satisfaction with the pre-retrofit lighting systems per space type and percent of corresponding respondents is shown in Table 10. The majority of respondents cited they were not satisfied or only somewhat satisfied with the lighting throughout their residence. The bedroom and living areas were most often cited as an area of dissatisfaction.

Table 10. Pre-Retrofit Lighting Satisfaction by Space Type

	Not Satisfied	Somewhat Satisfied	Neutral	Satisfied	Extremely Satisfied
Bathroom	29%	29%	8%	25%	8%
Bedroom	46%	21%	8%	21%	4%
Closet	38%	17%	4%	33%	8%
Kitchen	21%	25%	13%	29%	17%
Dining Area	29%	21%	13%	29%	8%
Living Area	38%	21%	8%	29%	4%

The average occupant is retired and at home 10-16 hours per day during both the summer and winter seasons. Table 11 provides the percentage of occupants per space type who cited a specific room where 'most of their time was spent'. The two top ranking spaces were the kitchen and living room. Fifty-nine percent of occupants cited the living area as the space where most of their time is spent, and 21 percent of occupants cited the kitchen as the space where most of their time is spent.

Table 11. Most Frequently Used Space in the Home – Self Reported

Space Type	Percent of Respondents Who Use Each Space Most Frequently
Bathroom	3%
Bedroom	10%
Closet	3%
Kitchen	21%
Dining Area	3%
Living Area	59%

Occupants were asked to rank the criteria that is most important to them when purchasing lighting products: lifetime, price, lighting color, light distribution, brightness, energy efficiency, lower energy bills and other. The top criteria selected was lower energy bills, followed by energy efficiency and price.

Occupants were asked to identify the space type they would improve the lighting in if possible. The overall response when asked to identify what type of improvement was needed was to 'make the spaces brighter'. Table 12 contains the percentage of occupants who selected each space type as their top choice.

Table 12. Space Identified for Lighting Improvement by Occupant (%)

Space Identified for Improvement	Percent of Respondents Identifying the Space as Most in Need of Improvement
Bathroom	30%
Bedroom	22%
Closet	0%
Kitchen	7%
Dining Area	4%
Living Area	37%

When asked to identify a typical task performed in their apartments that requires high quality lighting, 58 percent of respondents replied 'reading'. 33 percent of respondents replied that they were not satisfied with the pre-retrofit lighting for the identified task.

When asked to identify the issue most bothersome to them about lighting in general, 29 percent of respondents' responded 'flicker' and 25 percent identified 'cost'. Table 13 provides the issue options and percentage of occupants that identified each as most bothersome.

Table 13. Issue Identified by Occupants as Most Bothersome for General Lighting

Issue	Percent of Respondents Rating the Issue as Most Bothersome
Cost	25%
Early Failure	17%
Light Color	17%
Audible Noise	4%
Slow Start Time	8%
Flicker	29%

Product and Installation Costs

Lighting system procurement required multiple orders. For products with local manufacturer representatives, the representatives were utilized to verify the lighting design, verify the final product specification and provide product quotes for use with local distributors. The local distributor with the lowest quotation was selected. For products that are sold ‘off-the-shelf’, these were procured at the brick-and-mortar store by the project team. Table 14 provides the final costs associated with the lighting retrofit products for the total demonstration and for each individual apartment. Note, the cost of 4’ LED lamps included new ballasts and lamp sockets necessary to convert the existing fluorescent luminaire to LED. New vanity fixtures were required as the existing strip fixture utilized a T12 fluorescent lamp and suitable LED retrofit that could utilize the existing fixture was not available.

Table 14. Demonstration Material Costs

	Quantity	Price	Per Unit
Bathroom Vanity Luminaires	23	$ 4,267.31	$ 185.54
GU-24 LED Lamp	69	$ 1,905.78	$27.62
Fixture	23	$ 2,361.53	$102.67
Portables and Dome-Style Luminaires: LED A Lamps	128	$ 922.88	$ 7.21
Kitchen Strip Luminaires (T8)	24	$ 4,313.22	$ 179.71
Compatible ballasts	48	$ 719.76	$ 14.95
Lamp sockets	192	$ 66.01	$0.34
Demonstration TOTAL		$ 9503.41	
Apartment TOTAL		$ 395.97	

Prerequisite qualifications for the installation team were based on typical residential lighting applications. Contractors with knowledge of residential lighting code and previous experience in the residential sector were prioritized. The project was awarded to the low bid contractor for $4,196, or $174.83 per apartment.

The installation team worked in teams of two to minimize the time spent in each apartment. The retrofit lighting system in the living room, kitchen and bathroom spaces are provided in Figure 14 and Figure 15.

Figure 14. Post-Retrofit Lighting Conditions - Living Room

Source: CLTC

Figure 15. Post-Retrofit Lighting Conditions – Kitchen and Bathroom

Source: CLTC

The lighting system is owned by the demonstration site, who conducts maintenance duties on behalf of the tenants as requested. The GU-24 base lamps were new to the apartment configurations described in the *Demonstration Site* section. Operation of these lamps only differ during maintenance activities, and the maintenance team at the site was updated on the new systems in their buildings.

Post-Retrofit Measurement and Evaluation

The project team used two parallel paths to quantify the energy savings of the post-retrofit lighting system compared to the baseline system, lighting energy use data was collected per the *Measurement and Verification Plan* section of this report. Additional analysis was conducted using the lighting utilization data and the known lighting loads per room. Results for lighting energy use collected according to *Measurement and Verification Plan* are provided in Appendix F.

Lighting Utilization

Apartments were monitored from January 26, 2015 to April 17, 2015 (82 days) collect post-retrofit lighting utilization data based on the percentage of time lights were identified as ON for the monitoring period per space type. Table 15 and Table 16 provide post-retrofit lighting utilization per space type per apartment for control and retrofit apartments respectively. Space types reported as N/A did not have a light source available to monitor. Negative values indicate lighting use increased during the post-retrofit period, as compared to the baseline period.

Table 15. Lighting Utilization for Post-Retrofit Monitoring Period - Control Apartments

Apt	Bedroom	Bathroom	Closet	Dining	Hall	Kitchen Globe	Kitchen Wrap	Living Room
1	7.0%	1.2%	0.5%	8.0%	21.3%	0.4%	3.8%	22.3%
5	3.7%	5.1%	0.1%	15.6%	4.7%	1.4%	3.4%	0.5%
22	N/A	0.4%	10.2%	N/A	0.0%	4.5%	5.5%	0.0%
24	8.3%	7.6%	4.4%	20.3%	3.2%	1.3%	19.8%	0.3%
26	11.7%	3.8%	8.0%	1.2%	0.9%	6.4%	10.6%	6.2%
29	2.0%	1.2%	0.1%	0.1%	0.1%	0.1%	4.4%	0.8%
44	0.4%	0.0%	0.2%	0.2%	0.0%	0.0%	32.8%	0.0%
AVG	**5.5%**	**2.8%**	**3.4%**	**7.6%**	**4.3%**	**2.0%**	**11.5%**	**4.3%**

Table 16. Lighting Utilization for Post-Retrofit Monitoring Period – Retrofit Apartments

Apt	Bedroom	Bathroom	Closet	Dining	Hall	Kitchen Globe	Kitchen Wrap	Living Room
4	1.2%	0.0%	0.2%	21.6%	3.1%	0.4%	1.7%	0.0%
15	N/A	0.0%	0.4%	2.8%	2.3%	0.0%	4.4%	0.8%
17	N/A	2.5%	1.2%	2.6%	1.2%	9.0%	9.7%	6.8%
21	N/A	8.8%	2.1%	5.9%	2.4%	17.8%	0.4%	N/A
27	1.3%	6.3%	0.3%	3.6%	0.9%	13.0%	6.0%	0.3%
28	14.6%	2.4%	1.2%	15.4%	2.4%	9.1%	8.1%	13.2%
30	1.8%	1.0%	0.6%	0.3%	0.0%	6.2%	0.8%	0.1%
31	N/A	0.0%	0.1%	0.2%	N/A	0.0%	16.1%	12.9%
32	1.6%	1.2%	1.0%	0.0%	0.0%	26.9%	0.3%	0.1%
33	3.3%	14.4%	0.2%	0.0%	0.1%	0.0%	40.6%	31.0%
36	N/A	4.5%	4.1%	0.0%	1.9%	2.5%	1.4%	N/A
37	3.4%	6.9%	0.7%	35.6%	5.5%	0.5%	15.9%	0.2%
39	6.6%	1.9%	5.3%	2.8%	1.3%	8.4%	6.7%	14.6%
42	4.3%	7.7%	3.9%	1.9%	3.0%	0.4%	15.4%	9.9%
43	N/A	3.2%	0.3%	0.1%	2.4%	0.0%	0.0%	12.1%
AVG	**4.2%**	**4.1%**	**1.5%**	**6.6%**	**1.9%**	**6.7%**	**9.1%**	**7.5%**

Table 16 and Table 17 compare the pre-retrofit and post-retrofit lighting utilization data for control and retrofit apartments respectively. A positive difference indicates an increase in lighting utilization after the retrofit for the space type, and a negative difference indicates a decrease in lighting utilization after the retrofit for the space type.

Table 17. Lighting Utilization Difference between Pre and Post-Retrofit Monitoring Periods – Control Apartments

Apt	Bedroom	Bathroom	Closet	Dining	Hall	Kitchen Globe	Kitchen Wrap	Living Room
1	5.7%	0.0%	0.3%	-2.0%	21.3%	0.0%	-2.6%	-5.6%
5	-2.2%	0.9%	-0.6%	15.5%	2.5%	-2.9%	-1.4%	-43.2%
22	N/A	-3.0%	10.1%	N/A	0.0%	-30.7%	-22.1%	-0.4%
24	3.4%	-8.8%	-1.1%	1.3%	-3.8%	-6.2%	-6.0%	-11.3%
26	-1.9%	-4.9%	-0.8%	-2.3%	-0.2%	-5.3%	-6.1%	N/A
29	-0.7%	0.0%	-0.2%	0.0%	-0.1%	0.1%	-5.4%	-36.0%
44	-4.1%	-4.8%	0.0%	-0.4%	0.0%	0.0%	N/A	-3.8%
AVG	**0.0%**	**-2.9%**	**1.1%**	**2.0%**	**2.8%**	**-6.4%**	**-3.7%**	**-16.4%**

Table 18. Lighting Utilization Difference for Pre and Post-Retrofit Monitoring Periods – Retrofit Apartments

Apt	Bedroom	Bathroom	Closet	Dining	Hall	Kitchen Globe	Kitchen Wrap	Living Room
4	-2.8%	-0.5%	0.1%	13.8%	-4.5%	-2.6%	-3.3%	-6.7%
15	N/A	-64.7%	-0.1%	N/A	N/A	0.0%	-48.7%	0.4%
17	N/A	0.4%	0.6%	-1.8%	-7.9%	-31.9%	-0.3%	-16.7%
21	N/A	3.8%	-1.4%	-2.4%	-23.8%	17.7%	-6.0%	N/A
27	-7.5%	-4.9%	-2.5%	N/A	N/A	10.1%	0.3%	-3.7%
28	-8.4%	0.2%	1.1%	-4.4%	2.3%	-81.4%	1.6%	6.2%
30	0.3%	-0.5%	0.0%	-1.4%	-0.3%	4.6%	-11.2%	-0.7%
31	N/A	-1.1%	-0.1%	-5.0%	N/A	-0.5%	6.4%	-18.6%
32	N/A	-0.7%	0.1%	-0.1%	-0.1%	-15.2%	-1.7%	N/A
33	-12.4%	13.7%	-0.6%	0.0%	0.1%	0.0%	21.3%	-9.5%
36	N/A	-32.4%	0.6%	-21.4%	-0.1%	1.0%	1.1%	N/A
37	3.1%	5.2%	0.1%	12.2%	0.6%	-2.9%	-1.2%	-26.3%
39	4.6%	-1.6%	-4.3%	-3.7%	-3.6%	-2.8%	-0.4%	-0.8%
42	-5.0%	-0.2%	0.9%	1.6%	-1.2%	0.2%	-22.1%	-10.0%
43	N/A	1.2%	0.1%	-0.4%	N/A	-0.2%	-2.4%	-35.8%
AVG	**-3.8%**	**-5.4%**	**-0.3%**	**-1.0%**	**-3.1%**	**-6.5%**	**-3.8%**	**-11.2%**

On average, the length of day during the post-retrofit period was shorter than during the benchmark period. The decrease in lighting utilization for all space types for most apartments may be partially due to this factor. Other factors include resident vacations, full documentation of occupant travel is documented in raw survey responses provided in Appendix D and Appendix E.

Lighting Energy Use

The project team calculated the projected annual lighting energy use savings using the known pre-retrofit and post-retrofit lighting loads for each apartment, and the known lighting utilization during the post-retrofit period. This method eliminates variances introduced by occupant time-of-use changes, seasonal changes, weather and length of day. Pre-retrofit calculated annual lighting energy use is provided in Table 19. Post-retrofit calculated annual lighting energy use is provided in Table 20. The calculated annual lighting energy savings for the installation result in an average of 76.6 percent.

Table 19. Calculated Annual Lighting Energy Use (kWh) with Pre-retrofit Lighting System

Apt	Bedroom	Bathroom	Closet	Dining	Hall	Kitchen Globe	Kitchen Wrap	Living Room	Total
4	6.31	0.00	0.70	113.53	16.29	2.10	21.44	0.00	160.38
15	N/A	0.00	1.40	14.72	12.09	0.00	55.50	4.20	87.92
17	N/A	14.45	4.20	13.67	6.31	47.30	122.36	35.74	244.04
21	N/A	50.88	7.36	31.01	12.61	93.56	5.05	N/A	200.46
27	6.83	36.42	1.05	18.92	4.73	68.33	75.69	1.58	213.55
28	76.74	13.88	4.20	80.94	12.61	47.83	102.18	69.38	407.76
30	9.46	5.78	2.10	1.58	0.00	32.59	10.09	0.53	62.13
31	N/A	0.00	0.35	1.05	N/A	0.00	203.09	67.80	272.30
32	8.41	6.94	3.50	0.00	0.00	141.39	3.78	0.53	164.55
33	17.34	83.26	0.70	0.00	0.53	0.00	512.14	162.94	776.91
36	N/A	26.02	14.37	0.00	9.99	13.14	17.66	N/A	81.17
37	17.87	39.89	2.45	187.11	28.91	2.63	200.57	1.05	480.49
39	34.69	10.99	18.57	14.72	6.83	44.15	84.52	76.74	291.20
42	22.60	44.52	13.67	9.99	15.77	2.10	194.26	52.03	354.94
43	N/A	18.50	1.05	0.53	12.61	0.00	0.00	63.60	96.29
AVG	**22.3**	**23.4**	**5.0**	**32.5**	**9.9**	**33.0**	**107.2**	**41.2**	**274.7**

Table 20. Calculated Annual Lighting Energy Use (kWh) with Post-Retrofit Lighting System

Apt.	Bedroom	Bathroom	Closet	Dining	Hall	Kitchen Globe	Kitchen Wrap	Living Room	Total
4	1.00	0.00	0.17	17.98	2.58	0.33	6.25	0.00	28.31
15	N/A	0.00	0.33	2.33	1.91	0.00	16.19	0.67	21.43
17	N/A	6.00	1.00	2.16	1.00	7.49	35.69	5.66	59.00
21	N/A	21.12	1.75	4.91	2.00	14.81	1.47	N/A	46.06
27	1.08	15.12	0.25	3.00	0.75	10.82	22.08	0.25	53.34
28	12.15	5.76	1.00	12.82	2.00	7.57	29.80	10.99	82.08
30	1.50	2.40	0.50	0.25	0.00	5.16	2.94	0.08	12.83
31	N/A	0.00	0.08	0.17	N/A	0.00	59.24	10.74	70.22
32	1.33	2.88	0.83	0.00	0.00	22.39	1.10	0.08	28.62
33	2.75	34.56	0.17	0.00	0.08	0.00	149.38	25.80	212.73
36	N/A	10.80	3.41	0.00	1.58	2.08	5.15	N/A	23.03
37	2.83	16.56	0.58	29.63	4.58	0.42	58.50	0.17	113.26
39	5.49	4.56	4.41	2.33	1.08	6.99	24.65	12.15	61.67
42	3.58	18.48	3.25	1.58	2.50	0.33	56.66	8.24	94.62
43	N/A	7.68	0.25	0.08	2.00	0.00	0.00	10.07	20.08
AVG	**3.5**	**9.7**	**1.2**	**5.1**	**1.6**	**5.2**	**31.3**	**6.5**	**64.2**

Lifecycle Cost Analyses

Lifecycle cost analyses (LCA) were performed to determine the simple payback, incremental net present value (NPV) and internal rate of return (IRR) of the demonstration retrofit for the average apartment monitored. The LCA is based on the measured energy use, installation labor and material costs incurred during the course of the installation provided in the *System Procurement* and *Contractor Selection* sections of this report.

Simple payback is the initial investment divided by the annual savings experienced as a result of the investment, and is the number of years required to pay for the investment with the project savings. The incremental NPV is provided to determine if the retrofit lighting technology will have a positive or negative cash flow for the 15 year lifecycle analyzed. IRR estimates the growth of investment options, with the highest IRR being most likely to return 'strong growth'.[17] To determine the IRR, an assumed finance rate of 8% and reinvestment rate of 3% are used. An assumed inflation rate of 4% is used for LCA calculations.

Labor and material costs for replacing light sources are included at the lamp/luminaire's manufacturer-provided rated life. Based on typical residential lighting use of 1.8 hours a day[18] for 365 days a year, LED products with a life equal to or greater than 25,000 hours are expected to require replacement every 38 years in the residential application. Linear fluorescent T8 lamps with an estimated useful life of 24,000 hours are expected to require replacement every 37 years in the residential application. Compact

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[17] Internal Rate of Return. www.investopedia.com. January 2015.

[18] Department of Energy, *2010 U.S. Lighting Market Characterization*. Prepared by Navigant Consulting for DOE Solid-State Lighting Program, 2012, p. 59.

fluorescent lamps with an estimated useful life of 8,000 hours are expected to require replacement every 12 years in the residential application. Incandescent lamps with an estimated useful life of 2,000 hours are expected to require replacement every 3 years in the residential application.

Based on residential luminaire socket inventories provided in Table 1, the typical pre-retrofit apartment scenario is an incandescent lamp for medium base sockets at $2 per lamp. This assumption results in an assumed re-lamp of five sockets every three years in the LCA calculations.

For the energy cost calculations an average total rate of $0.16352/kWh was selected based on PG&E E-1 rate schedule for residential customers. [19] This energy rate is used with the calculated annual energy use during the monitoring period to determine the associate energy use costs of the lighting systems evaluated. No rebates were included in this analysis. LCA results for the retrofitted apartments excluding the cost of fixtures is provided in Table 20.

Table 21: Economic Analysis for LED Retrofits – LED Replacement Lamps Only

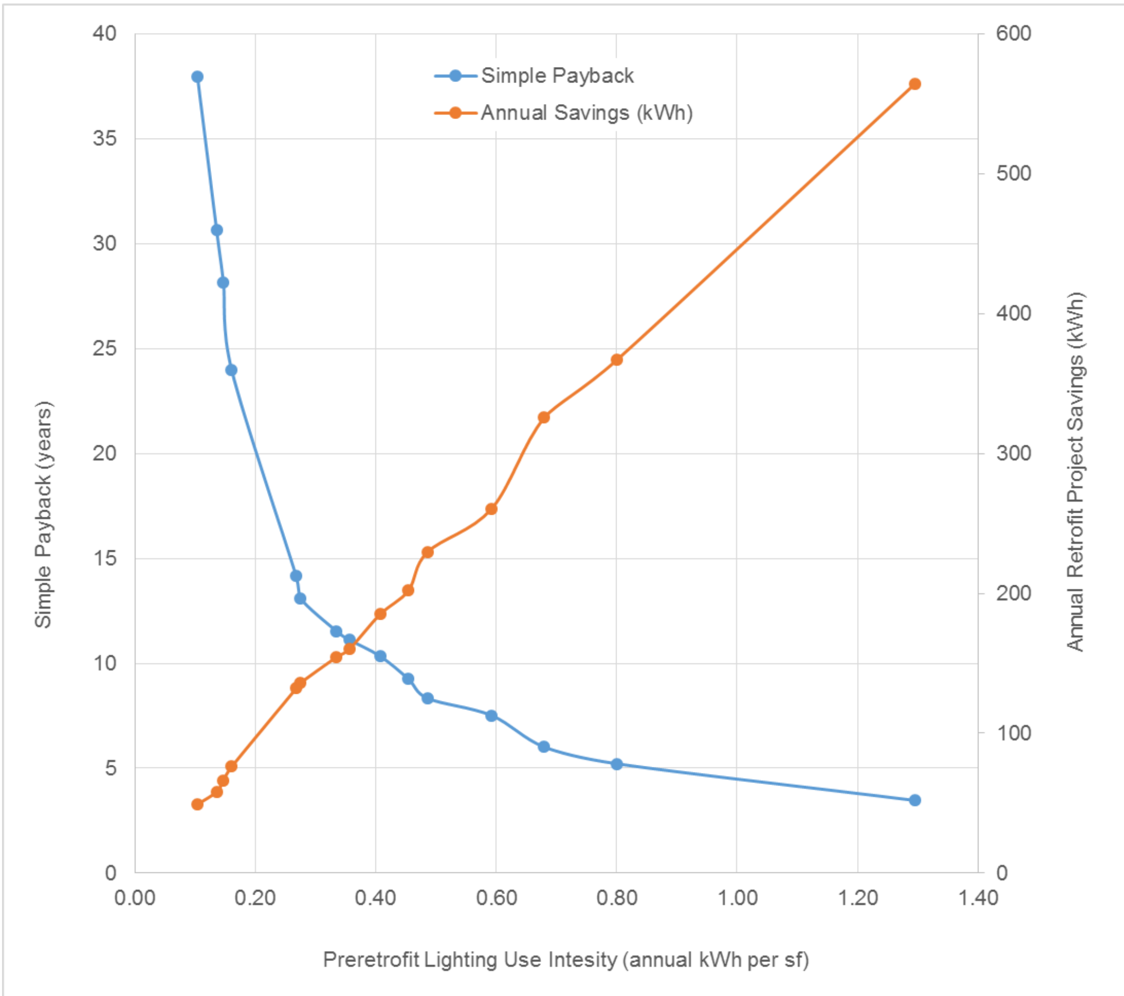
	No Labor (Self Installed)			With Labor		
Apt	**Simple Payback (Yrs.)**	**Incremental NPV**	**IRR (%)**	**Simple Payback (Yrs.)**	**Incremental NPV**	**IRR (%)**
4	14.2	-29	3%	22	-197	0%
15	28.1	-144	-1%	44	-312	-4%
17	10.3	57	5%	16	-111	2%
21	11.5	24	4%	18	-144	1%
27	11.1	34	4%	18	-134	1%
28	6.0	296	8%	9	128	5%
30	37.9	-174	-2%	60	-342	-5%
31	13.1	93	5%	15	-75	2%
32	3.5	-8	3%	21	-176	0%
33	30.7	713	12%	5	544	9%
36	5.2	-144	-1%	49	-312	-4%
37	8.3	375	9%	8	207	6%
39	7.5	134	6%	13	-34	3%
42	24.0	181	7%	12	13	4%
43	14.2	-120	0%	38	-288	-3%
AVG	**14.7**	**$86**	**4.1%**	**23**	**-$82**	**1%**

Based on this demonstration and assuming homeowners or maintenance staff install their own lamp replacements, LED lamp replacements under a multifamily, residential retrofit scenario are cost-effective if certain existing conditions are met. Homes where the existing annual lighting use intensity (kWh per square foot) is greater than approximately 0.25 results in a simple project payback of less than 15 years. Fifteen years represents a typical lighting project evaluation period. Eleven of 15 apartments, or approximately 73 percent of project participants experienced a payback within this timeframe. The

[19] PG&E. Electrical Schedule E-1 for Residential Services. March 1, 2015.

average payback and return on investment for these 11 units was nine years and 4.1 percent, respectively. Figure 16 shows the results of the cost analyses conducted following the 17 apartment retrofits. Results show annual retrofit savings (kWh) and simple payback (years) for each apartment as a function of pre-retrofit annual lighting energy intensity (kWh/sf).

Figure 16: Cost and Savings for LED Lamp Replacements in a Multifamily Residential Scenario



Analysis based on the total cost of A-lamp, GU24 and TLED replacements completed as part of the demonstration project. Costs do not include installation labor or ancillary fixtures or other parts purchased as part of the retrofit.

Occupant Survey

Responses from the post-retrofit occupant survey were collected from each participating retrofit apartment. Full responses of the post-retrofit survey are provided in Appendix E. Level of post-retrofit lighting satisfaction per space type was ranked with the percentage of respondents shown in Table 22.

Table 22. Post-Retrofit Lighting Satisfaction per Space Type

	Not Satisfied	Somewhat Satisfied	Neutral	Satisfied	Extremely Satisfied
Bathroom	6%	0%	6%	56%	31%
Bedroom	6%	6%	0%	75%	13%
Closet	0%	0%	6%	81%	6%
Kitchen	0%	0%	0%	19%	81%
Dining Area	0%	0%	0%	63%	31%
Living Area	0%	0%	13%	69%	19%

88 percent of respondents reported no change of lighting use or space use over the course of the study, with the average occupant spending 10-16 hours per day in the apartment during both the summer and winter seasons. Sixty-nine percent of respondents replied that they are home between the hours of 9 am to 5 pm 6-7 days per week. Seventy-five percent of respondents replied that the area where most of their time spent had not changed from the pre-retrofit survey where 59 percent of respondents cited the living area as the space where most of their time is spent, and 21 percent of occupants cited the kitchen as the space where most of their time was spent.

Following the retrofit, occupants were asked to re-rank the following criteria that is most important to them when purchasing lighting products: lifetime, price, lighting color, light distribution, brightness, energy efficiency, lower energy bills and other. The top criteria selected was lifetime followed by lower energy bills.

When asked which area of the apartment received the largest lighting improvement due to the lighting retrofit, 75 percent of respondents replied the kitchen. Table 23 contains the percentage of respondents per space type.

Table 23. Identified Space as Receiving Largest Improvement due to Lighting Retrofit

Identified Space as Receiving Largest Improvement due to Lighting Retrofit (%)	
Bathroom	38%
Bedroom	6%
Closet	6%
Kitchen	75%
Dining Area	0%
Living Area	0%

When asked to identify a typical task performed in their apartments that was most improved by the lighting retrofit, 44% of respondents replied ‘cooking’, 19% identified ‘reading’ and 19 percent identified ‘vanity tasks’ in the bathroom.

When asked which space type could be further improved with additional lighting modifications, 63 percent of respondents replied ‘bedroom’. When asked what they would improve about the lighting, 69 percent responding ‘nothing’ while 19 percent replied they would increase the ‘brightness’. When asked to identify the issue most bothersome to them about the new lighting, 94 percent of respondents responded ‘nothing’.

Eighty-eight percent of occupants found the installation process to be ‘not intrusive’. 63 percent of occupants found the installation of the monitoring and verification equipment to be ‘pleasant’ and 81 percent found the lighting retrofit installation to be ‘pleasant’.

CHAPTER 6: Conclusions and Recommendations

The demonstration of residential LED luminaires and lamp replacements documented in this report provides information useful for future installations of residential LED luminaires and lamp replacements, as well as providing general guidance for future installations of emerging technologies. Key areas with conclusions and recommendations for implementing LED luminaires and lamp replacements in residential applications include: energy savings and cost effectiveness, technology development, and end user acceptance.

Energy Savings and Cost Effectiveness

Annual lighting energy-use, calculated using lighting utilization data collected over the course of this demonstration, showed that the typical multifamily resident saved approximately 77 percent in lighting electricity annually by updating to LED luminaires and lamp replacements. Based on national residential lighting use studies, it is estimated that by replacing traditional light sources in a typical US residence homeowners can expect a simple payback of 3.2 years. Over a 15-year period, the incremental net present value of this project is estimated to be $1,084. While demonstrated energy savings are significant as compared to baseline systems, results in a multifamily scenario are cost-effective only under certain conditions. Homes where the existing annual lighting use intensity (kWh per square foot) is greater than approximately 0.25 results in a simple project payback of less than 15 years. Fifteen years represents a typical lighting project evaluation period. The site-specific combination of product costs and low lighting use levels result in an average project payback period of 14.7 years. Homeowners considering the switch from incandescent or CFL screw-base lamps only, based on outcomes of this demonstration and other published data, may expect a payback of 2-4 years. In addition, lighting utilization data also shows the space types in the home where lighting is used more frequently: the kitchen, living room and dining room. Focusing retrofits in these areas of the home will result in a more cost-effective lighting retrofit for the typical apartment resident.

Technology Development

Four-foot LED lamp replacement solutions that adhered to the residential lamp requirements of the project available for purchase at the time of this demonstration were minimal. In addition, the manufacturer of the selected product issued a recall for this lamp citing: Electrical arcing may cause the lamp to overheat and melt, posing a burn hazard. Development of cost-effective, safe, four-foot LED replacement lamps that meet the California energy efficiency standards is recommended to increase market adoption of residential LED lamps. In addition, at the time of this demonstration, there were limited commercialized products available that met the project criteria for GU-24 sockets. Additional development of cost-effective GU-24 LED replacement lamps compliant with California energy efficiency standards is recommended to address the GU-24 sockets unique to California homes.

End User Acceptance

Overall, survey data indicated occupants were pleased with their experience of the updated lighting system. When asked to identify the issue most bothersome to them about the new lighting system, 94 percent of respondents responded ‘nothing’.

Staff collected additional survey data to understand residential use patterns and identify areas most in need of lighting retrofits. Occupants were asked to rank the criteria that is most important to them when purchasing lighting products: lifetime, price, lighting color, light distribution, brightness, energy efficiency, lower energy bills and other. The top criteria selected was lifetime followed by lower energy bills suggesting that the long-life LED products were well-suited to residents’ needs.

When asked which area of the apartment received the largest lighting improvement due to the lighting retrofit, 75 percent of respondents replied the kitchen. The lighting utilization data indicates that the kitchen is also the space most used by occupants. Products developed specifically for high traffic areas of the home such as the kitchen are expected to be well-received and improve market adoption of LED technology.

FEIT ELECTRIC

LED LAMP

SPECIFICATIONS

enhance®
VIVID NATURAL LIGHT

SHOWS COLORS TRUE & NATURAL
92 CRI

Ideal For

Table Lamps | Floor Lamps | Ceiling Fans | Wall Sconces | Bath & Vanity

Features

- Instant On To Full Brightness
- Suitable For Damp Locations
- Dimmable
- UL Listed
- FCC Compliant
- RoHS Compliant
- 100% Mercury Free
- 5 Year Warranty
- Soft White
- Energy Star®

Benefits

- Full Range Dimming
- Energy Efficient: Up to 84% less energy than standard incandescent
- No Ultraviolet - Safe for artwork
- Color Consistency
- Low Heat
- Durable
- Long Life

ENERGY STAR

Specifications

Item Number	**Input Power** (Watts)	**Incandescent Equiv.** (Watts)	**Input Line Voltage**
BPAGOM800/927/LED	9.5	60	120
Base Type	**Lumens**	**Lumen Efficiency** (LPW)	**CCT**
E26 (Medium)	810	85	2700K
CRI	**Beam Angle**	**MOL**	**Diameter**
92	300°	4.6″	2.35″
Life Hours	**Minimum Starting Temperature**		
25,000	-13°F		

Feit Electric Company 4901 Gregg Rd. Pico Rivera, CA 90660 1-800-543-Feit www.feit.com

T8 Series

4' Linear LED Lamp

Product Description

The Cree® linear LED T8 lamp delivers up to 2800 lumens of enhanced spectrum 90+ CRI light while achieving up to 110 lumens per watt at the system level. The innovative design allows more uplight than standard LED tubes, thereby providing a more uniform light output. The T8 lamp is available in a wide array of color temperatures and operates using existing fluorescent T8 electronic instant start, programmed/rapid start and dimmable fluorescent ballasts. The T8 lamp is easy to install and fits into linear fluorescent fixtures, making it a perfect upgrade solution where energy savings and long life are critical.

4' LED Lamp
MOL- 48" (1219mm)

Performance Summary

- Upgrades existing T8 fluorescent lamps
- Utilizes Cree TrueWhite® Technology
- **System Efficacy:** 90 - 110 LPW at system level
- **Initial Delivered Lumens:** 1700-2800 lumens per LED lamp*
- **Lamp Watts:** As low as 16.5 watts*
- **CRI:** 90+
- **CCT:** 3000K, 3500K, 4000K, 5000K
- **Input Voltage:** 120-480 VAC, determined by fluorescent ballast
- **Rated Life:** 50,000 hours
- **Controls:** Dimmable (ballast dependent)
- **Mounting:** Linear fluorescent fixtures with dry or damp rating
- **Limited Warranty†:** 5 years

† See www.cree.com/lighting/products/warranty for warranty terms
* See wattage vs. lumen chart for lumens by specific ballast factor (BF)

Ordering Information

Example: LEDT8P 48 21L 40K B1

LEDT8P 48					
Product	**Initial Delivered Lumens**	**CCT**	**Voltage**	**Control**	**Options**
LEDT8P 48	**17L** 16.8W, 1700 lumens - 103 LPW **21L** 19.5W, 2100 lumens - 110 LPW	**30K** 3000K - Available in 17L only **35K** 3500K **40K** 4000K **50K** 5000K - Available in 17L only	**Blank** 120-480 Volt Ballast Dependent	**Blank** Dimmable	**B1** Single boxed lamps **T25** Tray pack lamp (Bulk Pack) - Available in 35K and 40K CCTs only

Rev. Date: V4 06/04/2015

Product Specifications

CREE TRUEWHITE® TECHNOLOGY

A revolutionary way to generate high-quality white light, Cree TrueWhite® Technology is a patented approach that delivers an exclusive combination of 90+ CRI, beautiful light characteristics and lifelong color consistency, all while maintaining high luminous efficacy – a true no compromise solution.

CONSTRUCTION & MATERIALS

- Lightweight aluminum heat sink housing provides strength and durability
- Shatterproof design
- Suitable for use with shunted and non-shunted sockets

OPTICAL SYSTEM

- Specialized lens design for optimal light distribution and smooth visual effect
- Measured and designed to achieve optimal light performance in existing fluorescent troffers

ELECTRICAL SYSTEM

- Integral, high-efficiency driver to remodulate current to LEDs
- Utilizes existing fluorescent ballast
- **Power Factor:** = 0.9 nominal
- **Input Power:** Ballast dependent
- **Input Voltage:** 120–277V, 347, 480V, 50/60Hz
- **Battery Backup:** Operates on fluorescent emergency ballasts
- **Operating Temperature Range:** -25˚C - + 45˚C (13˚F - + 113˚F)
- **Total Harmonic Distortion:** < 20%
- Not for use with T12 magnetic or electronic ballasts
- Not for use with T8 magnetic or HO ballasts
- Not for use or to be wired to "mains voltage"

CONTROLS

- Dimmable (ballast dependent)

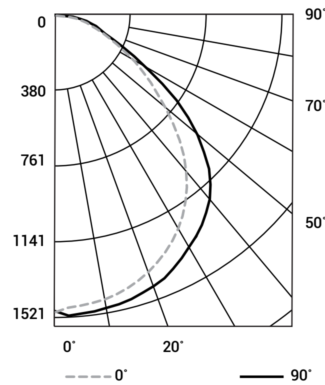
REGULATORY & VOLUNTARY QUALIFICATIONS

- UL Listed to UL 1993, UL 8750, CSA C22.2 No. 1993-12 & CSA C22.2 No. 250.13-12
- Suitable for damp locations
- Designed for indoor use
- DLC qualified when ordered with 21L product and 30K, 35K and 40K CCTs. Please refer to www.designlights.org/QPL for most current information

Photometry

(2) LEDT8P 48 21L 35K INSTALLED IN A 2 X 4 RECESSED TROFFER BASED ON CESTL REPORT TEST #: PL04179-001

Fixture photometry has been conducted by a NVLAP accredited testing laboratory in accordance with IESNA LM-79-08. IESNA LM-79-08 specifies the entire luminaire as the source resulting in a fixture efficiency of 100%.



Coefficients Of Utilization - Zonal Cavity Method				
RC %:	80			
RW %:	70	50	30	10
RCR: 0	119	119	119	119
1	109	105	101	97
2	100	92	86	81
3	92	82	74	68
4	84	73	64	58
5	78	65	57	50
6	72	59	50	44
7	67	54	45	39
8	62	49	41	35
9	58	45	37	32
10	55	42	34	29

Effective Floor Cavity Reflectance: 20%

Average Luminance Table (cd/m²)				
		Horizontal Angle		
		0°	45°	90°
Vertical Angle	45°	1,797	1,957	2,221
	55°	1,467	1,712	1,869
	65°	1,167	1,166	1,254
	75°	1,026	757	1,176
	85°	1,171	1,069	1,444

Zonal Lumen Summary			
Zone	Lumens	% Lamp	Luminaire
0–30	1,182	N/A	30.2%
0–40	1,944	N/A	49.6%
0–60	3,298	N/A	84.2%
0–90	3,918	N/A	100%
0–180	3,918	N/A	100%

Reference www.cree.com/Lighting/Products/Indoor/Lamps/T8-Series for detailed photometric data

Product Information

Product Number	UPC	Description	Lamp Type	CCT	Lamps per Pack	CRI	Initial Delivered Lumens	Rated Life (Hrs)
LEDT8P 48 21L 35K B1	849665001935	Linear LED T8 Replacement Lamp	T8	3500K	1	90	2100	50,000
LEDT8P 48 21L 40K B1	849665001942	Linear LED T8 Replacement Lamp	T8	4000K	1	90	2100	50,000
LEDT8P 48 17L 30K B1	849665001966	Linear LED T8 Replacement Lamp	T8	3000K	1	90	1700	50,000
LEDT8P 48 17L 35K B1	849665001973	Linear LED T8 Replacement Lamp	T8	3500K	1	90	1700	50,000
LEDT8P 48 17L 40K B1	849665001980	Linear LED T8 Replacement Lamp	T8	4000K	1	90	1700	50,000
LEDT8P 48 17L 50K B1	849665001997	Linear LED T8 Replacement Lamp	T8	5000K	1	90	1700	50,000

Watts vs. Lumens

LEDT8 48 21L				
		Lamp Watts	System Watts	Lamp Lumens (Bare)
Low	.77 Ballast Factor	16.5	18.0	1,877
Normal	.88 Ballast Factor	19.5	21.0	2,151
Normal	1.0 Ballast Factor	22.2	23.7	2,424
High	1.1 Ballast Factor	25.6	27.1	2,668
High	1.15 Ballast Factor	27.0	28.5	2,768
High	1.18 Ballast Factor	27.9	29.4	2,822

LEDT8 48 17L				
		Lamp Watts	System Watts	Lamp Lumens (Bare)
Low	.77 Ballast Factor	16.8	18.3	1,734
Normal	.88 Ballast Factor	19.9	21.4	1,973
Normal	1.0 Ballast Factor	23.5	25.0	2,229
High	1.1 Ballast Factor	26.7	28.2	2,421
High	1.15 Ballast Factor	28.1	29.6	2,504
High	1.18 Ballast Factor	29.1	30.6	2,555

US: www.cree.com/lighting T (800) 236-6800 F (262) 504-5415
Canada: www.cree.com/canada T (800) 473-1234 F (800) 890-7507

Illumis 13.7W GU24 90+ CRI A-Lamp

The world's first omni-directional GU24, to exceed 90 CRI.

Instant-on and high color rendering (90+CRI).

Omni-directional 300º beam angle.

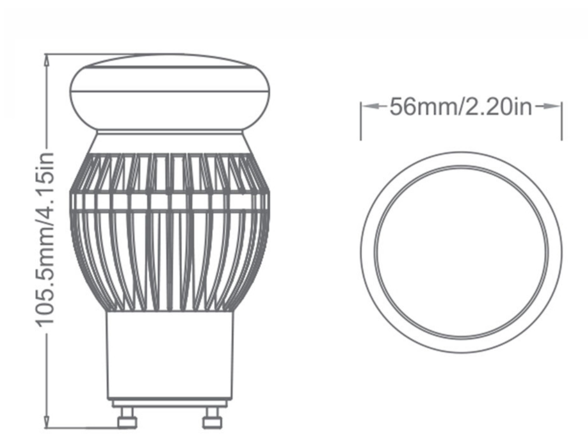
Consumes only 13.7W compared to a traditional 60W incandescent.

Outlasts CFL bulbs by 5-8 times.

Meets California Title 24 code.

3000k CCT generates a warm, welcoming light.

Reproduces vivid colors and natural skin tones.



Product Code	Power (W)	Lamp flux (lm)	Efficacy (lm/W)	CCT (K)	Voltage (VAC)	Base	CRI	Lifetime (hours)	Warranty (years)	Dimmable	Certificates
IL-BL-29-11.-O7B	13.7	825	60.2	3000	120	GU24	90	50000	5	Yes	UL, cUL, FCC, RoHS

TITLE 24 COMPLIANT · 90+ CRI · FC · UL · c UL us LISTED · RoHS Compliant · CE

www.illumislights.com

sales@illumislights.com

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HINKLEY LIGHTING, INC.
33000 PIN OAK PARKWAY | AVON LAKE, OHIO 44012
[PH] 440.653.5500 [F] 440.653.5555
HINKLEYLIGHTING.COM | FREDRICKRAMOND.COM

AVON 5552CM-GU24
CHROME

WIDTH:	14.5"
HEIGHT:	8.0"
WEIGHT:	4.0 LBS
MATERIAL:	METAL
GLASS:	ETCHED OPAL
BACKPLATE WIDTH:	7.3"
BACKPLATE HEIGHT:	4.5"
SOCKET:	2-18W GU24
EXTENSION:	6.3"
TTO:	5.8"
CERTIFICATION:	C-US DAMP RATED
VOLTAGE:	120V
UPC:	640665555486
INSTALL OPTIONS:	UP AND DOWN

AT HINKLEY, WE EMBRACE THE DESIGN PHILOSOPHY THAT YOU CAN MERGE TOGETHER THE LIGHTING, FURNITURE, ART, COLORS AND ACCESSORIES YOU LOVE INTO A BEAUTIFUL ENVIRONMENT THAT DEFINES YOUR OWN PERSONAL STYLE. WE HOPE YOU WILL BE INSPIRED BY OUR COMMITMENT TO KEEP YOUR 'LIFE AGLOW.'

life AGLOW®

WattNode® Pulse Output kWh Transducer Connection Instructions

For use with HOBO® H21, H22, U30, UX90, and UX120 series data loggers, and HOBO data nodes

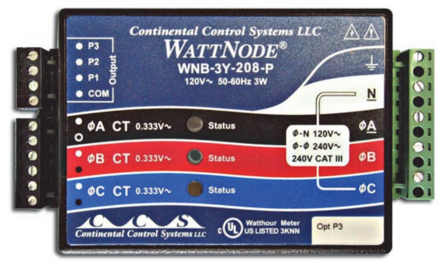
Applies to these WattNode Pulse Output kWh Transducers:

Onset Part No.	Configuration / VAC	Output	Maximum Pulse Output	WattNode Part No.
T-WNB-3Y-208	Single-phase 120 or Wye 208-240	Pulses representing kWh	4 Hz	WNB-3Y-208-P
T-WNB-3Y-208-P	Single-phase 120 or Wye 208-240	Pulses representing kWh	4 Hz	WNB-3Y-208-P option P3
T-WNB-3D-240	Delta 208-240	Pulses representing kWh	4 Hz	WNB-3D-240-P
T-WNB-3D-480	Delta (or Wye) 480	Pulses representing kWh	4 Hz	WNB-3D-480-P

DANGER!—HIGH VOLTAGE HAZARD

Installing transducers in an energized electrical enclosure or on any energized conductor can result in severe injury or death. These transducers are for installation by qualified personnel only. To avoid electrical shock, do not perform any installation or servicing of these transducers unless you are qualified to do so. Disconnect and lock-out all power sources during installation and servicing. Please read transducer user manuals for instructions and use.

This document provides instructions on connecting the WattNode Pulse Output kWh Transducers listed above to HOBO H21, H22, U30, UX90, and UX120 series data loggers and to ZW series data nodes. **Note:** For information on connecting the kWh transducer to the power source and other transducer details, refer to the WattNode documentation provided by Continental Control Systems.



WattNode Pulse Output kWh Transducer
(Onset Part No. T-WNB-3Y-208-P shown)

Required

- Selected WattNode Pulse Output kWh Transducer
- Appropriately rated Current Transducer(s)
- Smart Sensor-compatible HOBO data logger (H21, H22, or U30 series) with:
  - Pulse Input Adapter(s), Onset Part No: S-UCC-M00x*
  - HOBOware® Pro Software, version 2.2 or higher (2.4 or higher for U30)
- 22 AWG twisted pair wire (customer supplied) for UX120 series with HOBO Pro Software, version 3.2.0 or higher
- Pulse input-compatible HOBO data node (ZW series) and HOBO data logger (UX90 series) with:
  - Onset Part No: CABLE-2.5-STEREO*
  - HOBOware Pro Software, version 3.0 or higher for ZW series and version 3.3 or higher for UX90 series

* For monitoring power demand as well as generated power, a second S-UCC-M00x pulse input adapter (for H21, H22, or U30 series) or CABLE-2.5-STEREO (for pulse input-compatible ZW series) is required (at output terminal P2).

WattNode Pulse Output kWh Transducer Features

- The WattNode transducer includes three LEDs—one per phase—for diagnostics and indication of power direction, low power factor, and correctly installed CTs.
- The WattNode transducer provides bidirectional power measurements (positive and negative power). It can be used for conventional power and energy measurement as well as for net metering and PV applications. For monitoring power demand as well as generated power, a second S-UCC-M00x pulse input adapter (for H21, H22, or U30 series) or CABLE-2.5-STEREO (for pulse input-compatible ZW series) is required (at output terminal P2).

Manual Part No: MAN-WATTNODE
Doc No: 10332-K

- The T-WNB-3Y-208-P can measure two or three separate branch circuits simultaneously. Note that an S-UCC-M00x pulse input adapter (for H21, H22, or U30 series) or a CABLE-2.5-STEREO (for pulse input-compatible ZW series) is required for each circuit monitored.

Note: Refer to the *WattNode WNB Series Installation and Operation Manual* for details of these features.

Configuring the System

To configure the system, refer to the applicable connection diagram that corresponds to your electrical power configuration. Also refer to the WattNode manual for additional configurations.

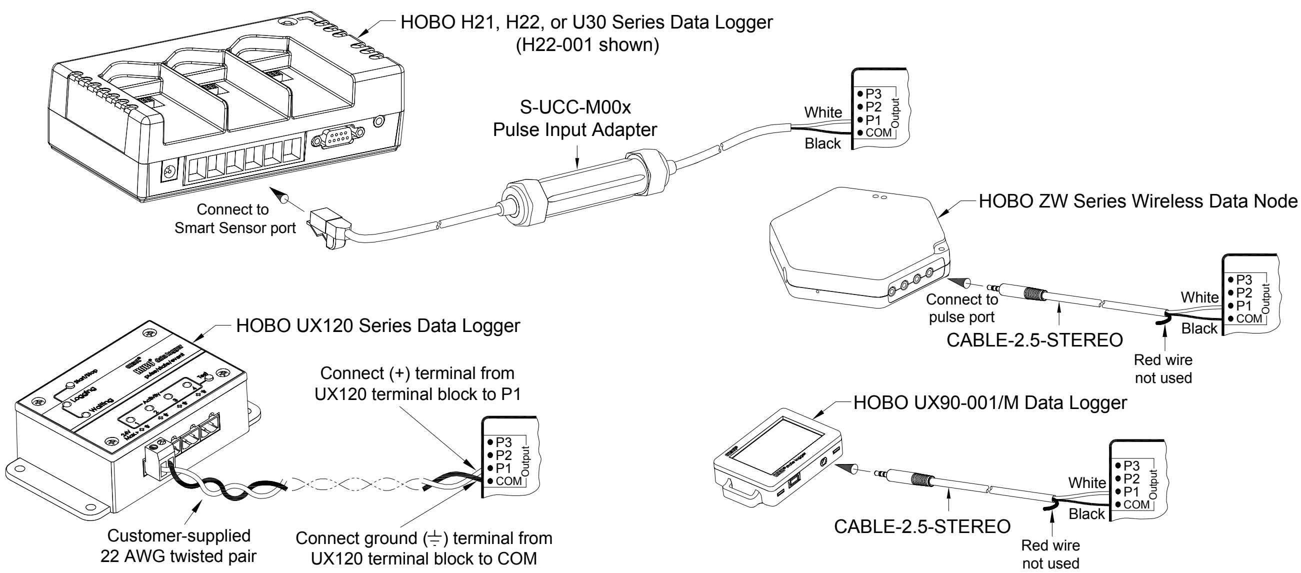


Figure 1: Connecting HOBO Data Logger or Data Node to WattNode

Electrical Service Types

Below is a list of service types, with connections and recommended WattNode models. Note: the WattNode ground connection improves measurement accuracy, but is not required for safety.

Model	Type	Phase to Neutral	Phase to Phase	Electrical Service Types*
WNB-3Y-208-P	Wye	120 VAC	208–240 VAC	1 Phase 2 Wire 120V with neutral 1 Phase 3 Wire 120V/240V with neutral 3 Phase 4 Wire Wye 120V/208V with neutral
WNB-3D-240-P	Delta or Wye	120–140 VAC	208–240 VAC	1 Phase 2 Wire 208V (No neutral) 1 Phase 2 Wire 240V (No neutral) 1 Phase 3 Wire 120V/240V with neutral 3 Phase 3 Wire Delta 208V (No neutral) 3 Phase 4 Wire Wye 120V/208V with neutral 3 Phase 4 Wire Delta 120/208/240V with neutral
WNB-3D-480-P	Delta or Wye	277 VAC	480 VAC	3 Phase 3 Wire Delta 480V (No neutral) 3 Phase 4 Wire Wye 277V/480V with neutral 3 Phase 4 Wire Delta 240/415/480V with neutral

*The wire count does NOT include ground. It only includes neutral (if present) and phase wires.

Single-Phase Two-Wire with Neutral

This configuration is most often seen in homes and offices. The two wires are neutral and line. For these models, the WattNode is powered from the **N** and **ØA** terminals.

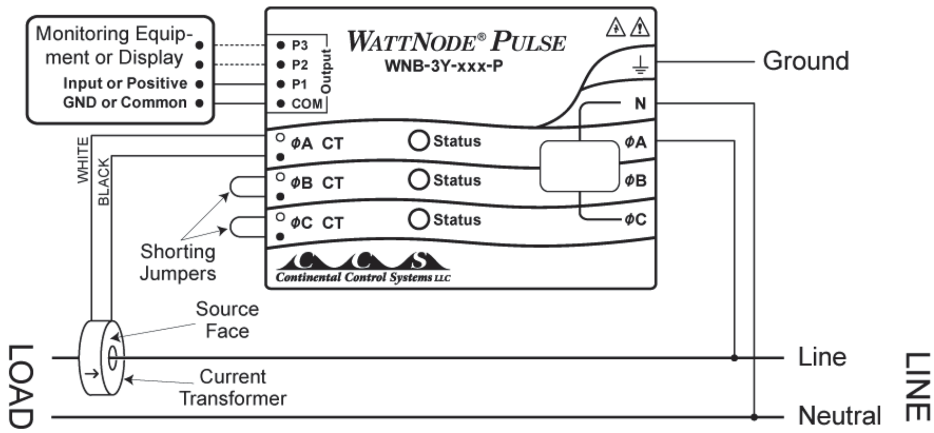


Figure 2: Single-Phase Two-Wire Connection

Recommended WattNode Model

The following table shows the WattNode model that should be used, depending on the line to neutral voltage.

Line to Neutral Voltage	WattNode Model
120 VAC	WNB-3Y-208-P

Single-Phase Three-Wire

This configuration is seen in North American residential and commercial service with 240 VAC for large appliances. The three wires are neutral and two line voltage wires with AC waveforms 180° out of phase; this results in 120 VAC between either line wire (phase) and neutral, and 240 VAC (or sometimes 208 VAC) between the two line wires (phases).

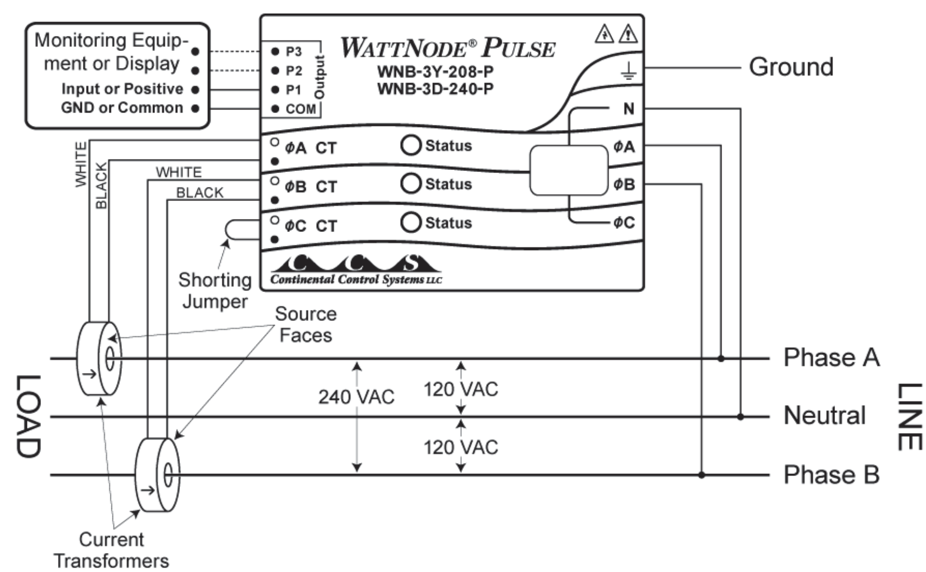


Figure 3: Single-Phase Three-Wire Connection

Recommended WattNode Models

The following table shows the WattNode models that can be used. If neutral may or may not be present, you should use the WNB-3D-240-P (see *Single-Phase Two-Wire without Neutral* below). If neutral is present, it must be connected for accurate measurements. If phase B may not be present, you should use the WNB-3Y-208-P (see *Single-Phase Two-Wire with Neutral* above).

WattNode Power Source	WattNode Model
N and **ØA** (Neutral and Phase A)	WNB-3Y-208-P
ØA and **ØB** (Phase A and Phase B)	WNB-3D-240-P

Single-Phase Two-Wire without Neutral

This is seen in residential and commercial service with 208 to 240 VAC for large appliances. The two wires are two line voltage wires with AC waveforms 120° or 180° out of phase. Neutral is not used. This results in 240 VAC (or 208 VAC) between the two line wires (phases). For this configuration, the WattNode is powered from the **ØA** and **ØB** (phase A and phase B) terminals.

For best accuracy, we recommend connecting the WattNode **N** (neutral) terminal to earth ground. This will not cause ground current to flow because the neutral terminal is not used to power the WattNode.

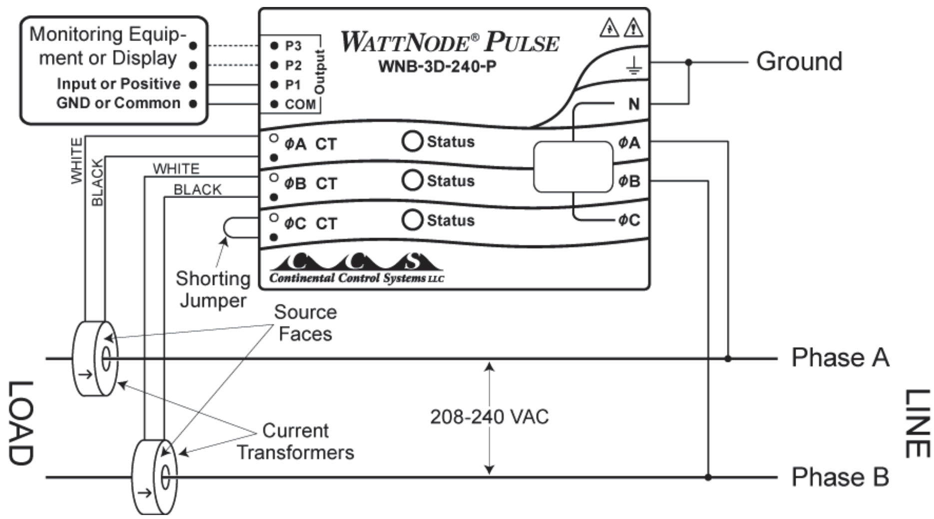


Figure 4: Single-Phase Two-Wire without Neutral Connection

Recommended WattNode Model

This configuration is normally measured with one WattNode model.

Phase-to-Phase Voltage	WattNode Model
208 - 240 VAC	WNB-3D-240-P

However, if neutral is available, then you may also use the WNB-3Y-208-P model. If you use the WNB-3Y-208-P, you will need to hook up the WattNode as shown in section *Single-Phase Three Wire* and connect neutral. You will need two CTs.

Grounded Leg

In rare cases (non-residential), one of the lines (phase A or phase B) may be grounded. You can check for this by using a multimeter (DMM) to measure the voltage between each phase and ground. If you see a reading between 0 and 5 VAC, that leg (phase) is probably grounded.

The WattNode will correctly measure circuits with a grounded leg, but the measured voltage and power for the phase will be zero and the status LED will not light for whichever phase is grounded, because the voltage is near zero. If you have a grounded leg configuration, you can save money by removing the CT for the grounded phase, since all the power will be measured on the non-grounded phase. We recommend putting the grounded leg (phase) on the **ØB** input and attaching a note to the WattNode indicating this configuration for future reference.

Three-Phase Four-Wire Wye

This is typically seen in commercial and industrial environments. The wires are neutral and three power lines with AC waveforms shifted 120° between the successive phases. With this configuration, the line voltage wires may be connected to the **ØA**, **ØB**, and **ØC** terminals in any order, so long as the CTs are connected to matching phases. It is important that you connect **N** (neutral). For these models, the WattNode is powered from the **N** and **ØA** terminals.

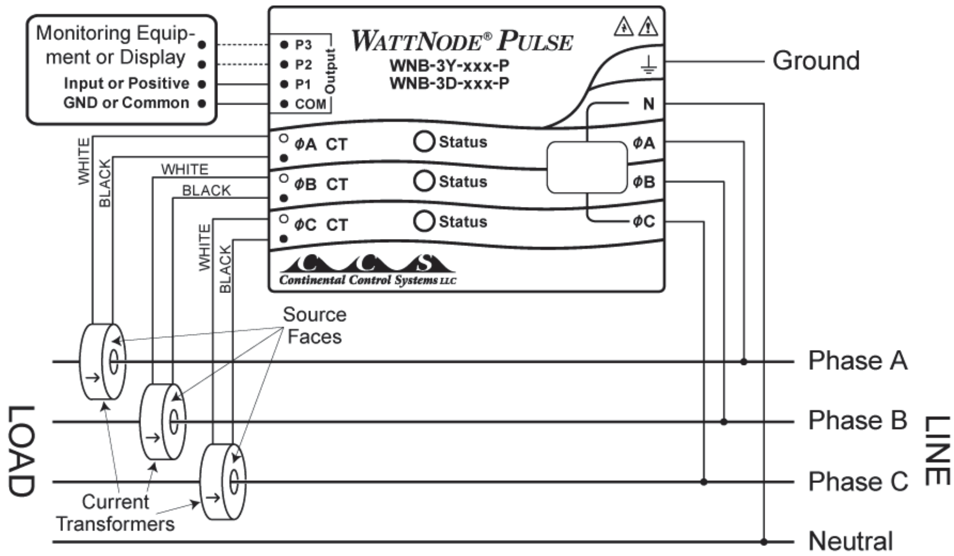


Figure 5: Three-Phase Four-Wire Wye Connection

Recommended WattNode Models

The following table shows the WattNode model that should be used, depending on the line to neutral voltage and line to line voltage (also called phase to phase voltage).

Line to Neutral Voltage	Line to Line Voltage	WattNode Model
120 VAC	208 VAC	WNB-3Y-208-P

Note: you may also use the following delta WattNode models to measure three-phase four-wire wye circuits. The only difference is that delta WattNode models are powered from **ØA** and **ØB**, rather than **N** and **ØA**. If neutral is present, it must be connected for accurate measurements.

Line to Neutral Voltage	Line to Line Voltage	WattNode Model
120 - 140 VAC	208 - 240 VAC	WNB-3D-240-P
277 VAC	480 VAC	WNB-3D-480-P

Three-Phase Three-Wire Delta (No Neutral)

This is typically seen in manufacturing and industrial environments. There is no neutral wire, just three power lines with AC waveforms shifted 120° between the successive phases. With this configuration, the line voltage wires may be connected to the **ØA**, **ØB**, and **ØC** terminals in any order, so long as the CTs are connected to matching phases. For these models, the WattNode is powered from the **ØA** and **ØB** (phase A and phase B) terminals. Note: all delta WattNode models provide a neutral connection **N**, which allows delta WattNode models to measure both wye and delta configurations.

For best accuracy, we recommend connecting the **N** (neutral) terminal to earth ground. This is not necessary on balanced three-phase circuits, where the ground-to-phase A, ground-to-phase B, and ground-to-phase C voltages are all roughly the same. This will not cause ground current to flow because the neutral terminal is not used to power the WattNode.

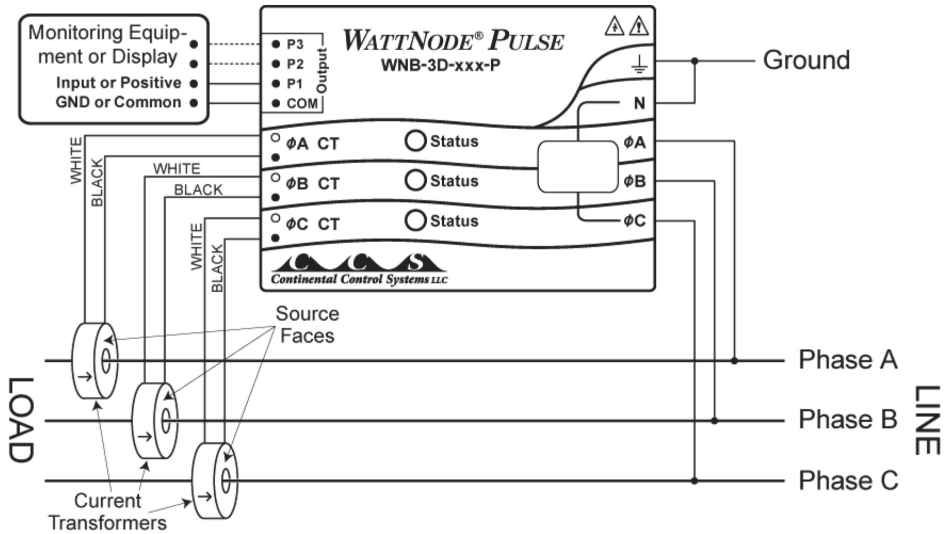


Figure 6: Three-Phase Three-Wire Delta (No Neutral) Connection

Recommended WattNode Models

The following table shows the WattNode model that should be used, depending on the line to neutral voltage and line to line voltage (also called phase to phase voltage).

Line to Line Voltage	WattNode Model
208 - 240 VAC	WNB-3D-240-P
480 VAC	WNB-3D-480-P

Grounded Leg

In rare cases, one of the phases may be grounded. You can check for this by using a multimeter (DMM) to measure the voltage between each phase and ground. If you see a reading between 0 and 5 VAC, that leg is probably grounded.

The WattNode will correctly measure circuits with a grounded leg, but the measured voltage and power for the phase will be zero and the status LED will not light for whichever phase is grounded, because the voltage is near zero. Also, one or both of the active (non-grounded) phases may show yellow or red/yellow LED flashing because the grounded leg configuration results in unusual power factors.

For optimum accuracy with a grounded leg, you should also connect the **N** (neutral) terminal on the WattNode to the ground terminal; this will not cause any ground current to flow because the neutral terminal is not used to power the WattNode. If you have a grounded leg configuration, you can save money by removing the CT for the grounded phase, since all the power will be measured on the non-grounded phases. We recommend putting the grounded leg on the **ØC** (Phase C) input and attaching a note to the WattNode indicating this configuration for future reference.

Separate Branch Circuits Connection (T-WNB-3Y-208-P** only)

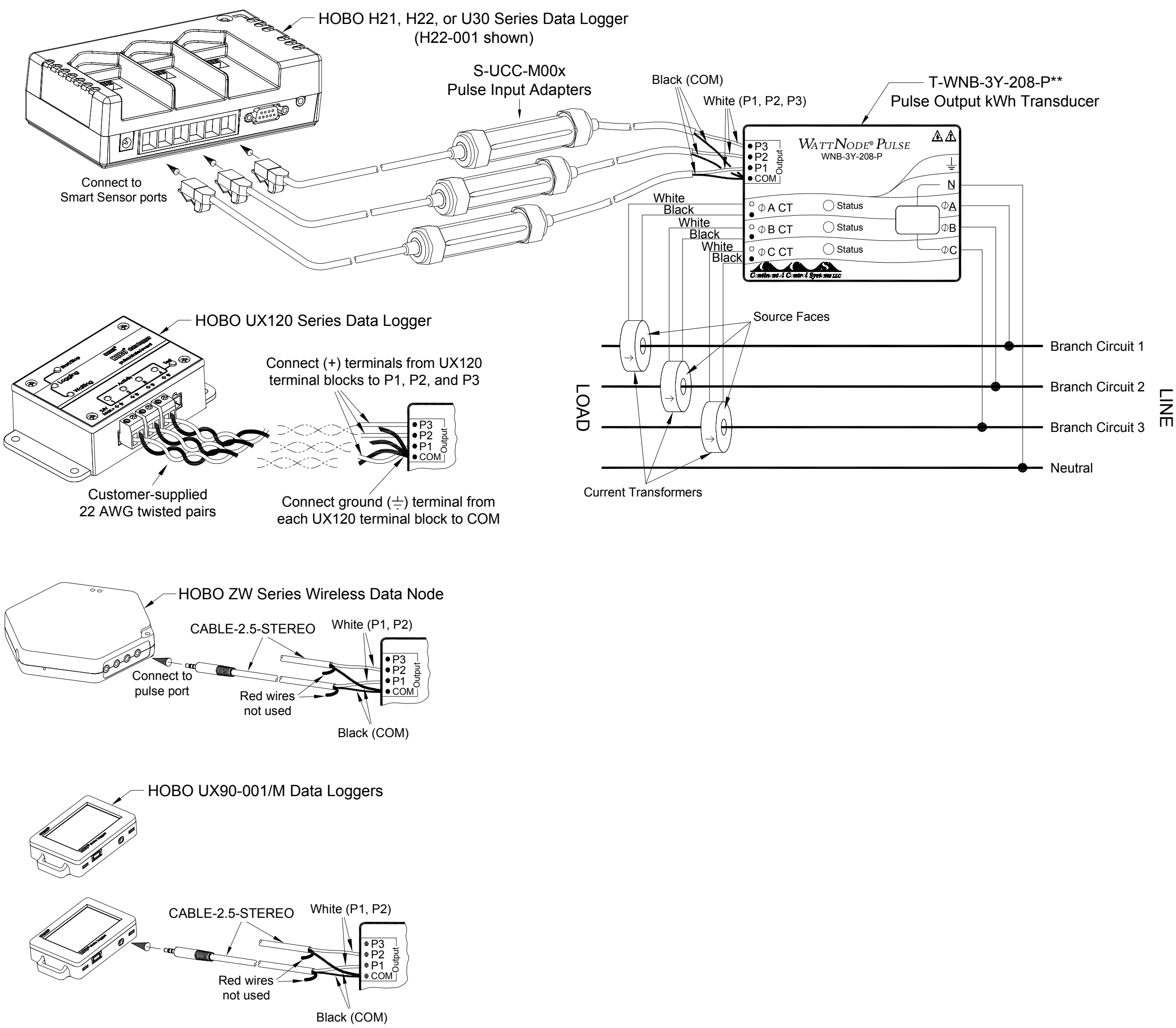


Figure 7: Separate Branch Circuits Connection

** The T-WNB-3Y-208-P can measure two or three separate branch circuits simultaneously. Note that a S-UCC-M00x pulse input adapter (if used with H21, H22, or U30 data loggers) or a CABLE-2.5-STEREO (if used with ZW data node or UX90 logger pulse ports) is required for each circuit monitored. A three-branch circuit arrangement is shown for H21, H22, U30, and UX120 data loggers.

WattNode® Pulse

Installation and Operation Manual

- WNB-3Y-208-P
- WNB-3Y-400-P
- WNB-3Y-480-P
- WNB-3Y-600-P
- WNB-3D-240-P
- WNB-3D-400-P
- WNB-3D-480-P

CCS
Continental Control Systems LLC
http://www.ccontrolsys.com

Rev V17b
(M5)

Information in this document is subject to change without notice.

Printed in the United States of America.
Document Number: WNB-P-V17b
Revision Date: November 30, 2011

Continental Control Systems, LLC.
3131 Indian Rd., Suite A
Boulder, CO 80301
(303) 444-7422
FAX: (303) 444-2903
E-mail: techsupport@ccontrolsys.com
Web: http://www.ccontrolsys.com

FCC Information

This equipment has been tested and complies with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

The FCC limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- Reorient or relocate the receiving antenna.
- Increase the separation between the equipment and receiver.
- Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.
- Consult the dealer or an experienced radio/TV technician to help.

Contents

Overview

Congratulations on your purchase of the WattNode® Pulse watt/watt-hour transducer/meter. It accurately measures energy and power in a compact package. The WattNode meter can fit in existing electric service panels avoiding the costly installation of sub-panels and associated wiring. It is designed for use in demand side management (DSM), sub-metering, and energy monitoring applications. The WattNode meter generates pulses proportional to total watt-hours. The pulse rate or frequency is proportional to the instantaneous power. Models are available for single-phase and three-phase, wye and delta configurations for voltages from 120 Vac to 600 Vac at 50 and 60 Hz.

Pulse Outputs

The WattNode meter generates pulse outputs using one or more optoisolators (also called photocouplers). These provide 5000 Vac of electrical isolation. The pulse outputs can interface to monitoring or data logging hardware without concerns about interference, ground loops, shock hazard, etc.

The standard Pulse WattNode meter makes bidirectional power measurements (energy consumption and energy production). It can be used for conventional power and energy measurement as well as for net metering and photovoltaic (PV) applications.

- ***Option P3*** - The per-phase measurement option measures one, two, or three separate branch circuits with a single meter, saving money and space.
- ***Option PV*** - The photovoltaic option measures residential PV systems. One WattNode meter measures the bidirectional total house energy, and the PV (or wind) generated energy. See **Manual Supplement MS-10: Option PV (Photovoltaic)** for details.
- ***Options DPO*** - The dual positive outputs option behaves exactly like the standard bidirectional model, but with the addition of a second positive pulse output channel (on the **P3** output terminal). This allows you to connect to two devices, such as a display and a data logger. See **Manual Supplement MS-11: Option DPO (Dual Positive Outputs)** for details.

See **Model Options (p. 30)** in the **Specifications** section below for details and more options.

Diagnostic LEDs

The Pulse WattNode meter includes three diagnostic LEDs—one per phase. During normal operation, these LEDs flash on and off, with the speed of flashing roughly proportional to the power on each phase. The LEDs flash green for positive power and red for negative power. Other conditions are signaled with different LED patterns. See the **Installation LED Diagnostics (p. 20)** section for full details.

Current Transformers

The WattNode meter uses solid-core (toroidal), split-core (opening), and bus-bar style current transformers (CTs) with a full-scale voltage output of 0.33333 Vac. Split-core and bus-bar CTs are easier to install without disconnecting the circuit being measured. Solid-core CTs are more compact, generally more accurate, and less expensive, but installation requires that you disconnect the circuit to install the CTs.

Additional Literature

- WattNode Advanced Pulse - Quick Install Guide
- Manual Supplement MS-10: Option PV (Photovoltaic)
- Manual Supplement MS-11: Option DPO (Dual Positive Outputs)
- Manual Supplement MS-17: Option PW (Pulse Width)
- Manual Supplement MS-19: Option SSR (Solid-State Relay)

Front Label

This section describes all the connections, information, and symbols that appear on the front label.

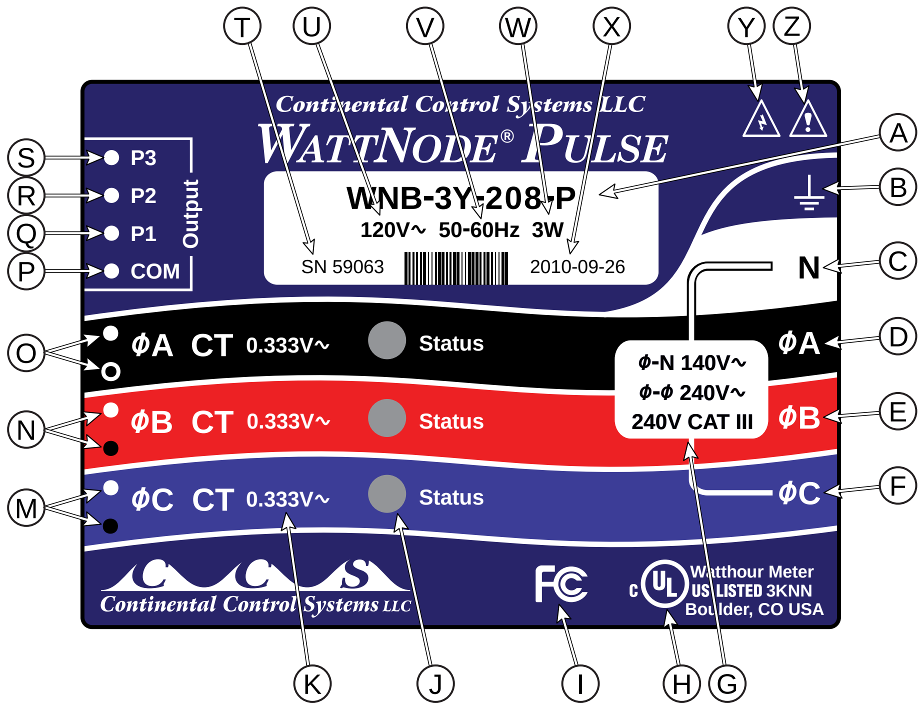


Figure 1: Front Label Diagram

A: WattNode model number. The "**WNB**" indicates a second generation WattNode meter with diagnostic LEDs and up to three pulse output channels. The "**3**" indicates a three-phase model. The "**Y**" or "**D**" indicates wye or delta models, although delta models can measure wye circuits (the difference is in the power supply). The "**208**" (or other value) indicates the nominal line-to-line voltage. Finally, the "**P**" indicates pulse output.

B: Functional ground. This terminal should be connected to earth ground if possible. It is not required for safety grounding, but ensures maximum meter accuracy.

C: Neutral. This terminal "**N**" should be connected to neutral when available.

D, E, F: Line voltage inputs. These terminals connect to the ***ϕ*A** (phase A), ***ϕ*B** (phase B), and ***ϕ*C** (phase C) electric mains. On wye models the meter is powered from ***ϕ*A** and **N** terminals. On delta models, the meter is powered from the ***ϕ*A** and ***ϕ*B** terminals.

G: Line voltage measurement ratings. This block lists the nominal line-to-neutral "***ϕ*-N 120V~**" voltage, line-to-line "***ϕ*-*ϕ* 240V~**" voltage, and the rated measurement voltage and category "**240V CAT III**" for this WattNode model. See the Specifications (p. 30) for more information about the measurement voltage and category.

H: UL Listing mark. This shows the UL and cUL (Canadian) listing mark and number "**3KNN**".

I: FCC Mark. This logo indicates that the meter complied with part 15 of the FCC rules.

J: Status LEDs. These are status LEDs used to verify and diagnose meter operation. See Installation LED Diagnostics (p. 20) for details.

K: Current transformer (CT) voltage rating. These markings "**0.333V~**" indicate that the meter must be used with CTs that generate a full-scale output of 0.333 Vac (333 millivolts).

M, N, O: Current transformer (CT) inputs. These indicate CT screw terminals. Note the white and black circles at the left edge of the label: these indicate the color of the CT wire that should be inserted into the corresponding screw terminal. The terminals marked with black circles are connected together internally.

P: Pulse output common (COM). This is the common terminal for all three pulse output channels. This terminal should be more negative than the **P1**, **P2**, and **P3** terminals (unless the meter was ordered with ***Option SSR***).

Q, R, S: Pulse outputs (P1, P2, P3). These are the pulse output channels. Different models use one, two, or three channels. They should always be positive relative to the common terminal.

T: Serial number. This shows the meter serial number and options if any are selected. The barcode contains the serial number in Code 128C format.

U: Mains supply rated voltage. This is the rated supply voltage for this model. The **V~** indicates AC voltage. For wye models, this voltage should appear between the **N** and ***ϕ*A** terminals. For delta models, this voltage should appear between the ***ϕ*A** and ***ϕ*B** terminals.

V: Mains frequencies. This indicates the rated mains frequencies for the meter.

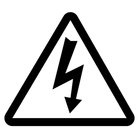
W: Maximum rated power. This is the maximum power consumption (watts) for this model.

X: Manufacture date. This is the date of manufacture for the WattNode meter.

Y: Caution, risk of electrical shock. This symbol indicates that there is a risk of electric shock when installing and operating the meter if the installation instructions are not followed correctly.

Z: Attention - consult Manual. This symbol indicates that there can be danger when installing and operating the meter if the installation instructions are not followed correctly.

Symbols

	Attention - Consult Installation and Operation Manual	Read, understand, and follow all instructions in this Installation and Operation Manual including all warnings, cautions, and precautions before installing and using the product.
	Caution – Risk of Electrical Shock	Potential Shock Hazard from Dangerous High Voltage.
	CE Marking	Complies with the regulations of the European Union for Product Safety and Electro-Magnetic Compatibility. ● Low Voltage Directive – EN 61010-1: 2001 ● EMC Directive – EN 61327: 1997 + A1/1998 + A2/2001

Installation

Precautions

DANGER — HAZARDOUS VOLTAGES
WARNING - These installation/servicing instructions are for use by qualified personnel only. To avoid electrical shock, do not perform any servicing other than that contained in the operating instructions unless you are qualified to do so.

Always adhere to the following checklist:

1) Only qualified personnel or **licensed electricians** should install the WattNode meter. The mains voltages of 120 Vac to 600 Vac can be lethal!
2) Follow all applicable local and national electrical and safety codes.
3) Install the meter in an electrical enclosure (panel or junction box) or in a limited access electrical room.
4) Verify that circuit voltages and currents are within the proper range for the meter model.
5) Use only UL recognized current transformers (CTs) with built-in burden resistors, that generate 0.333 Vac (333 millivolts AC) at rated current. **Do not use current output (ratio) CTs such as 1 amp or 5 amp output CTs: they will destroy the meter and may create a shock hazard.** See **Current Transformers (p. 35)** for CT maximum input current ratings.
6) Ensure that the line voltage inputs to the meter are protected by fuses or circuit breakers (not needed for the neutral wire). See **Circuit Protection (p. 16)** for details.
7) Equipment must be disconnected from the HAZARDOUS LIVE voltages before access.
8) The terminal block screws are **not** insulated. Do not contact metal tools to the screw terminals if the circuit is live!
9) Do not place more than one line voltage wire in a screw terminal; use wire nuts instead. You may use more than one CT wire per screw terminal.
10) Before applying power, check that all the wires are securely installed by tugging on each wire.
11) Do not install the meter where it may be exposed to temperatures below –30°C or above 55°C, excessive moisture, dust, salt spray, or other contamination. The meter requires an environment no worse than pollution degree 2 (normally only non-conductive pollution; occasionally, a temporary conductivity caused by condensation must be expected).
12) Do not drill mounting holes using the meter as a guide; the drill chuck can damage the screw terminals and metal shavings can fall into the connectors, causing an arc risk.
13) If the meter is installed incorrectly, the safety protections may be impaired.

Electrical Service Types

Below is a list of service types, with connections and recommended models. Note: the ground connection improves measurement accuracy, but is not required for safety.

Model	Type	Line-to-Neutral	Line-to-Line	Electrical Service Types
WNB-3Y-208-P	Wye	120 Vac	208–240 Vac	1 Phase 2 Wire 120V with neutral 1 Phase 3 Wire 120V/240V with neutral 3 Phase 4 Wire Wye 120V/208V with neutral
WNB-3Y-400-P	Wye	230 Vac	400 Vac	1 Phase 2 Wire 230V with neutral 3 Phase 4 Wire Wye 230V/400V with neutral
WNB-3Y-480-P	Wye	277 Vac	480 Vac	3 Phase 4 Wire Wye 277V/480V with neutral 1 Phase 2 Wire 277V with neutral
WNB-3Y-600-P	Wye	347 Vac	600 Vac	3 Phase 4 Wire Wye 347V/600V with neutral
WNB-3D-240-P	Delta or Wye	120–140 Vac	208–240 Vac	1 Phase 2 Wire 208V (no neutral) 1 Phase 2 Wire 240V (no neutral) 1 Phase 3 Wire 120V/240V with neutral 3 Phase 3 Wire Delta 208V (no neutral) 3 Phase 4 Wire Wye 120V/208V with neutral 3 Phase 4 Wire Delta 120/208/240V with neutral
WNB-3D-400-P	Delta or Wye	230 Vac	400 Vac	3 Phase 3 Wire Delta 400V (no neutral) 3 Phase 4 Wire Wye 230V/400V with neutral
WNB-3D-480-P	Delta or Wye	277 Vac	480 Vac	3 Phase 3 Wire Delta 480V (no neutral) 3 Phase 4 Wire Wye 277V/480V with neutral 3 Phase 4 Wire Delta 240/415/480V with neutral

**The wire count does NOT include ground. It only includes neutral (if present) and phase wires.*

Table 1: WattNode Models

Single-Phase Two-Wire with Neutral

This configuration is most often seen in homes and offices. The two conductors are neutral and line. For these models, the meter is powered from the **N** and **ϕA** terminals.

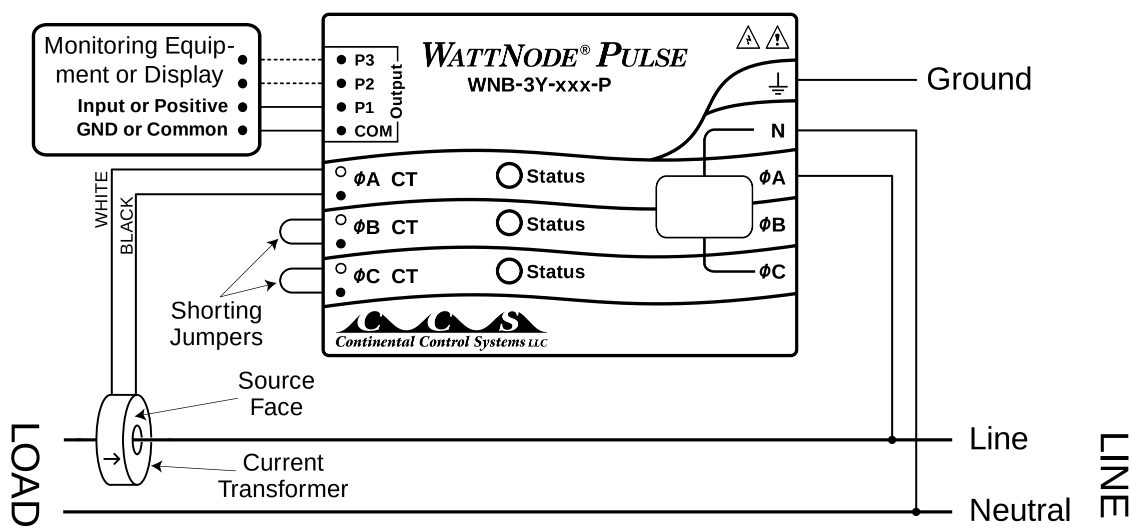


Figure 2: Single-Phase Two-Wire Connection

Recommended WattNode Models

The following table shows the WattNode models that should be used, depending on the line to neutral voltage.

Line to Neutral Voltage	WattNode Model
120 Vac	WNB-3Y-208-P
230 Vac	WNB-3Y-400-P
277 Vac	WNB-3Y-480-P

Single-Phase Three-Wire (Mid-Point Neutral)

This configuration is seen in North American residential and commercial service with 240 Vac for large appliances. The three conductors are a mid-point neutral and two line voltage wires with AC waveforms 180° out of phase; this results in 120 Vac between either line conductors (phase) and neutral, and 240 Vac (or sometimes 208 Vac) between the two line conductors (phases).

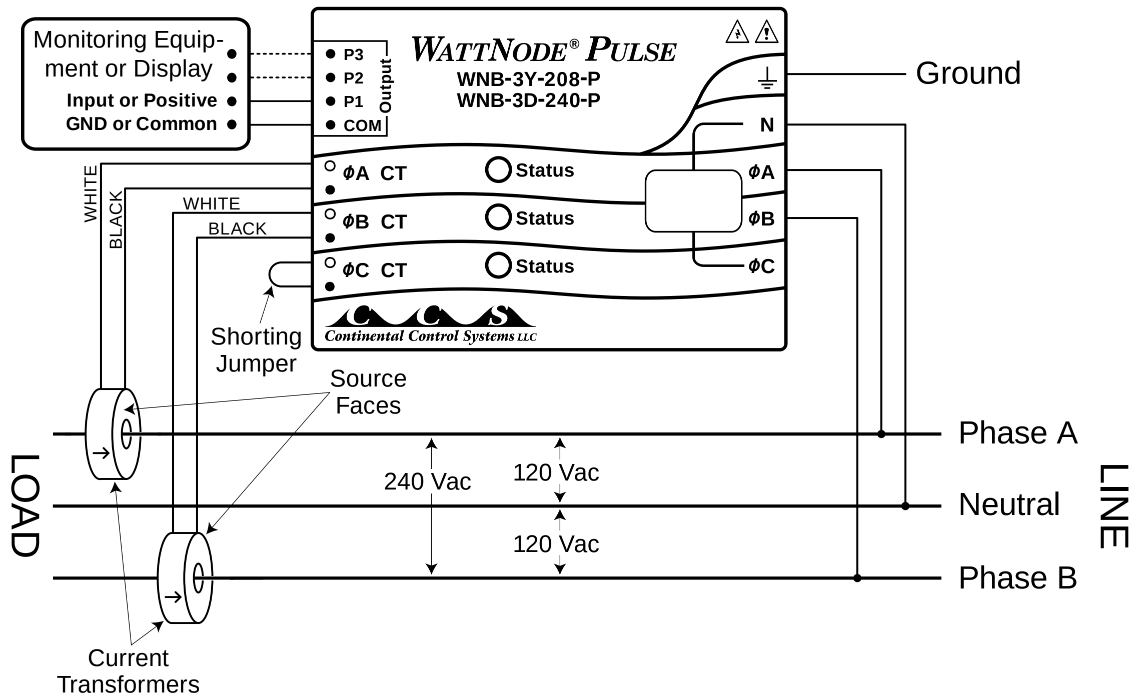


Figure 3: Single-Phase Three-Wire Connection

Recommended WattNode Models

The following table shows the WattNode models that can be used. If neutral may or may not be present, you should use the WNB-3D-240-P (see **Single-Phase Two-Wire without Neutral** below). If neutral is present, it must be connected for accurate measurements. If phase B may not be present, you should use the WNB-3Y-208-P (see **Single-Phase Two-Wire with Neutral** above).

Meter Power Source	WattNode Model
N and **ϕA** (Neutral and Phase A)	WNB-3Y-208-P
ϕA and **ϕB** (Phase A and Phase B)	WNB-3D-240-P

Single-Phase Two-Wire without Neutral

This is seen in residential and commercial service with 208 to 240 Vac for large appliances. The two conductors have AC waveforms 120° or 180° out of phase. Neutral is not used. For this configuration, the meter is powered from the ***ϕ*A** and ***ϕ*B** (phase A and phase B) terminals.

For best accuracy, we recommend connecting the **N** (neutral) terminal to the ground terminal. This will not cause ground current to flow because the neutral terminal does not power the meter.

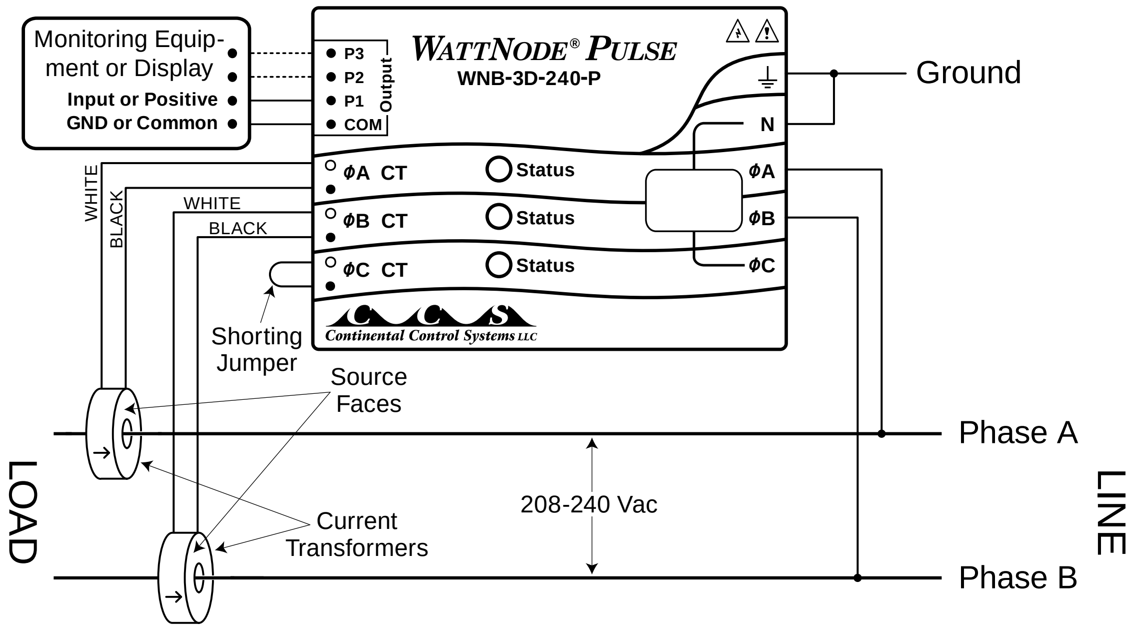


Figure 4: Single-Phase Two-Wire without Neutral Connection

Recommended WattNode Model

This configuration is normally measured with the following WattNode model.

Line-to-Line Voltage	WattNode Model
208 - 240 Vac	WNB-3D-240-P

If neutral is available, you may also use the WNB-3Y-208-P model. If you use the WNB-3Y-208-P, you will need to hook up the meter as shown in section **Single-Phase Three-Wire (Mid-Point Neutral)** and connect neutral. You will need two CTs.

If one of the conductors (phase A or phase B) is grounded, see **Grounded Leg Service** below for recommendations.

Three-Phase Four-Wire Wye

This is typically seen in commercial and industrial environments. The conductors are neutral and three power lines with AC waveforms shifted 120° between phases. The line voltage conductors may be connected to the **ϕA**, **ϕB**, and **ϕC** terminals in any order, **so long as the CTs are connected to matching phases**. It is important that you connect **N** (neutral) for accurate measurements. For wye "**-3Y**" models, the meter is powered from the **N** and **ϕA** terminals.

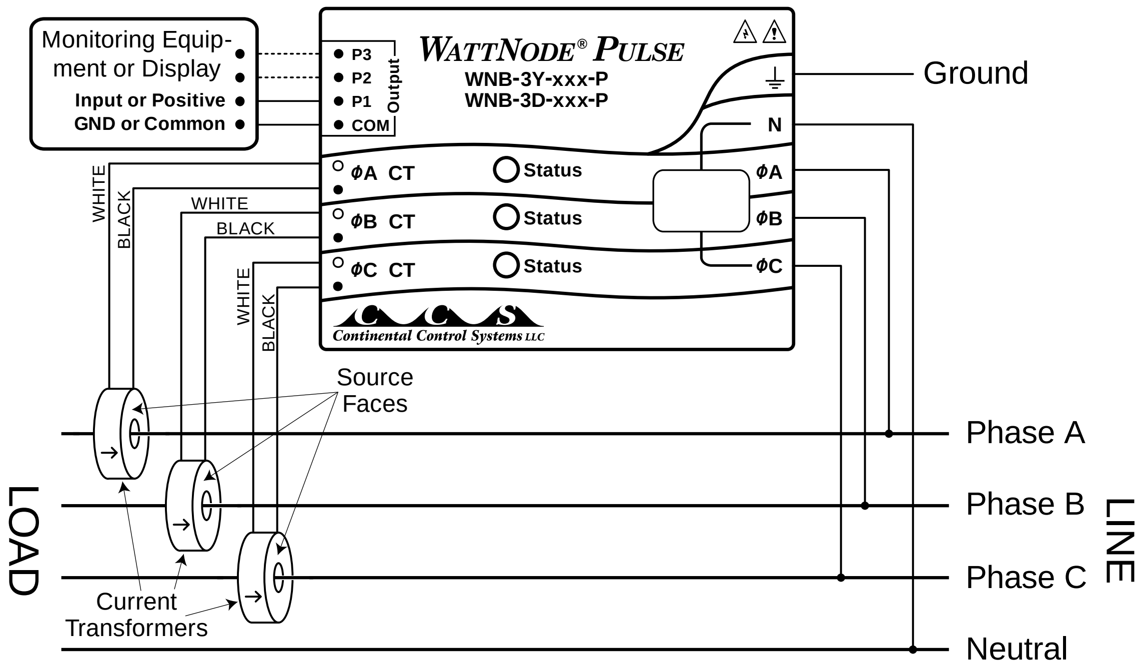


Figure 5: Three-Phase Four-Wire Wye Connection

Recommended WattNode Models

The following table shows the WattNode models that should be used, depending on the line-to-neutral voltage and line-to-line voltage (also called phase-to-phase voltage).

Line-to-Neutral Voltage	Line-to-Line Voltage	WattNode Model
120 Vac	208 Vac	WNB-3Y-208-P
230 Vac	400 Vac	WNB-3Y-400-P
277 Vac	480 Vac	WNB-3Y-480-P
347 Vac	600 Vac	WNB-3Y-600-P

Note: you may also use the following delta WattNode models to measure three-phase four-wire wye circuits. The only difference is that delta WattNode models are powered from **ϕA** and **ϕB**, rather than **N** and **ϕA**. If neutral is present, it must be connected for accurate measurements.

Line-to-Neutral Voltage	Line-to-Line Voltage	WattNode Model
120 - 140 Vac	208 - 240 Vac	WNB-3D-240-P
230 Vac	400 Vac	WNB-3D-400-P
277 Vac	480 Vac	WNB-3D-480-P

Three-Phase Three-Wire Delta Without Neutral

This is typically seen in manufacturing and industrial environments. There is no neutral wire, just three power lines with AC waveforms shifted 120° between the successive phases. With this configuration, the line voltage wires may be connected to the **ϕA**, **ϕB**, and **ϕC** terminals in any order, **so long as the CTs are connected to matching phases**. For these models, the meter is powered from the **ϕA** and **ϕB** (phase A and phase B) terminals. Note: all delta WattNode models provide a neutral connection **N**, which allows delta WattNode models to measure both wye and delta configurations.

For best accuracy, we recommend connecting the **N** (neutral) terminal to earth ground. This will not cause ground current to flow because the neutral terminal is not used to power the meter.

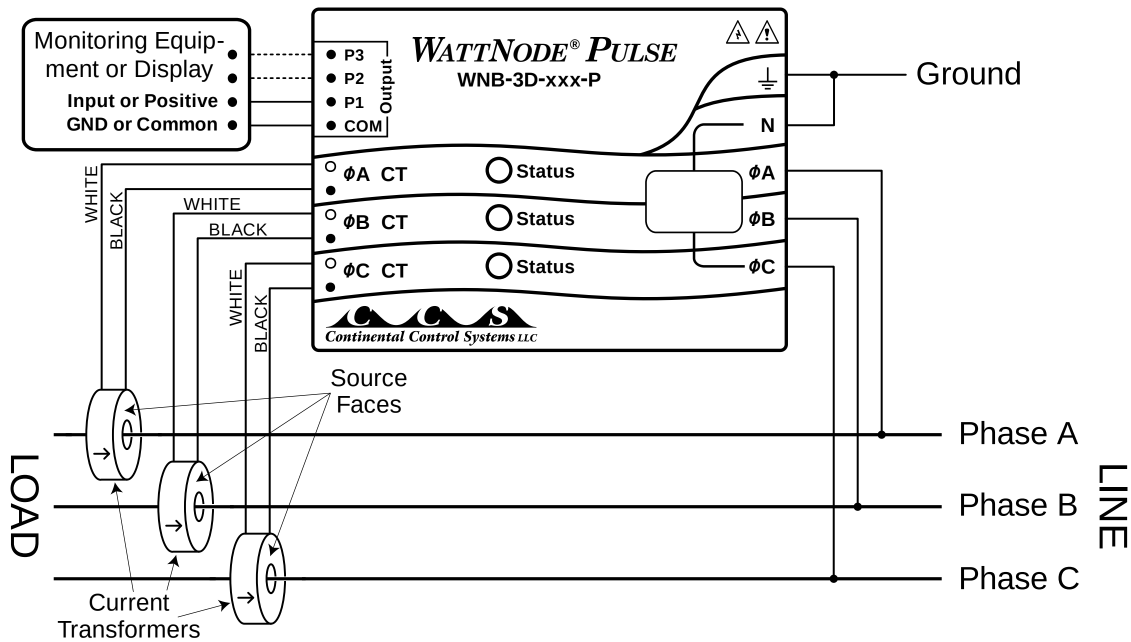


Figure 6: Three-Phase Three-Wire Delta Connection

Recommended WattNode Models

The following table shows the WattNode models that should be used, depending on the line-to-line voltage (also called phase-to-phase voltage).

Line-to-Line Voltage	WattNode Model
208 - 240 Vac	WNB-3D-240-P
400 Vac	WNB-3D-400-P
480 Vac	WNB-3D-480-P

Three-Phase Four-Wire Delta (Wild Leg)

The uncommon four-wire delta electrical service is a three-phase delta service with a center-tap on one of the transformer windings to create a neutral for single-phase loads.

See http://www.ccontrolsys.com/w/Four_Wire_Delta_Circuits for details.

Grounded Leg Service

In rare cases with delta services or single-phase two-wire services without neutral, one of the phases may be grounded. You can check for this by using a multimeter (DMM) to measure the voltage between each phase and ground. If you see a reading between 0 and 5 Vac, that leg is probably grounded (sometimes called a “grounded delta”).

The WattNode meter will correctly measure services with a grounded leg, but the measured power for the grounded phase will be zero and the status LED will not light for whichever phase is grounded, because the voltage is near zero.

For optimum accuracy with a grounded leg, you should also connect the **N** (neutral) terminal on the meter to the ground terminal; this will not cause any ground current to flow because the neutral terminal is not used to power the meter. If you have a grounded leg configuration, you can save money by removing the CT for the grounded phase, since all the power will be measured on the non-grounded phases. We recommend putting the grounded leg on the **ϕB** or **ϕC** inputs and attaching a note to the meter indicating this configuration for future reference.

Mounting

Protect the WattNode meter from moisture, direct sunlight, high temperatures, and conductive pollution (salt spray, metal dust, etc.) If moisture or conductive pollution may be present, use an IP 66 or NEMA 4 rated enclosure to protect the meter. Due to its exposed screw terminals, the meter must be installed in an electrical service panel, an enclosure, or an electrical room. The meter may be installed in any orientation, directly to a wall of an electrical panel or junction box.

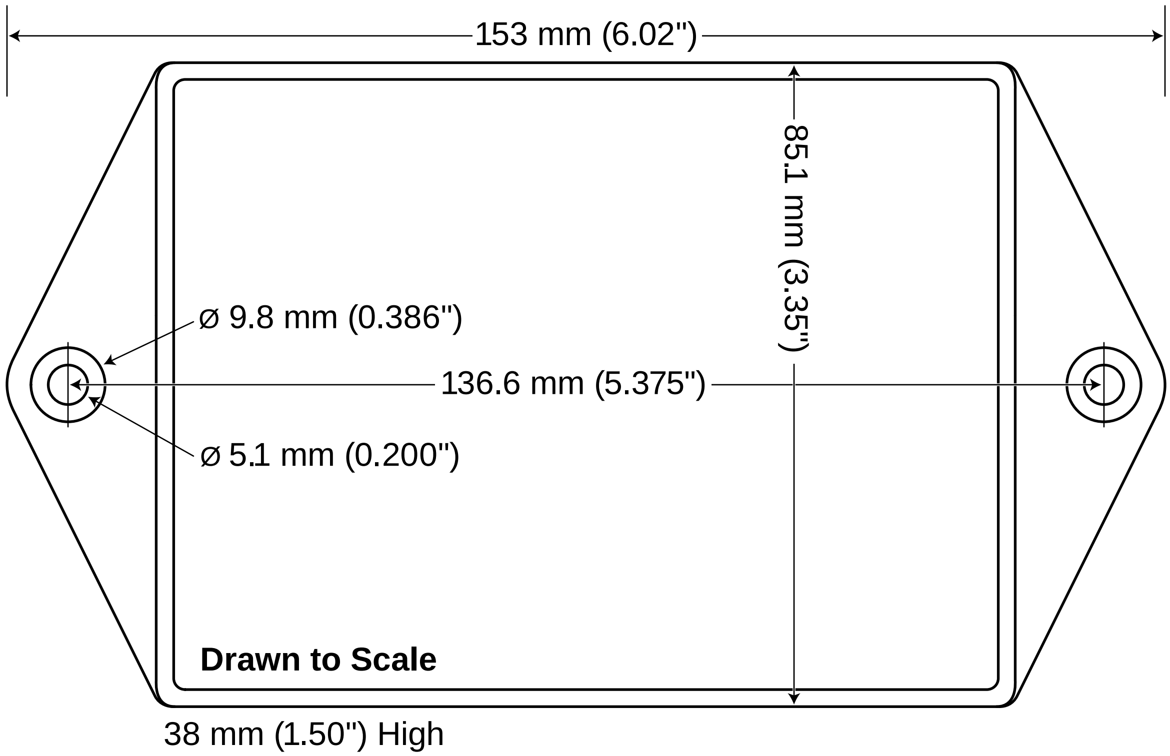


Figure 7: WattNode Meter Dimensions

The WattNode meter has two mounting holes spaced 5.375 inches (137 mm) apart (center to center). These mounting holes are normally obscured by the detachable screw terminals. Remove the screw terminals by pulling outward while rocking from end to end. The meter or **Figure 7** may be used as a template to mark mounting hole positions, but **do not drill the holes with the meter in the mounting position** because the drill may damage the connectors and leave drill shavings in the connectors.

You may mount the meter with the supplied #8 self-tapping sheet metal screws using 1/8 inch pilot hole (3.2 mm). Or you may use hook-and-loop fasteners. If you use screws, avoid over-tightening which can crack the case. If you don't use the supplied screws, the following sizes should work (**bold** are preferred); use washers if the screws could pull through the mounting holes

Screw Style	U.S.A. UTS Sizes	Metric Sizes
Pan Head or Round Head	#6, **#8**, #10	M3.5, **M4**, M5
Truss Head	**#6**, #8	**M3.5**, M4
Hex Washer Head (integrated washer)	#6, **#8**	M3.5, **M4**
Hex Head (add washer)	#6, **#8**, #10	M3.5, **M4**, M5

Table 2: Mounting Screws

Selecting Current Transformers

The rated full-scale current of the CTs should normally be chosen somewhat above the maximum current of the circuit being measured (see **Current Crest Factor** below for more details). In some cases, you might select CTs with a lower rated current to optimize accuracy at lower current readings. Take care that the maximum allowable current for the CT can not be exceeded without tripping a circuit breaker or fuse; see **Current Transformers (p. 35)**.

We only offer CTs that measure AC current, not DC current. Significant DC current can saturate the CT magnetic core, reducing the AC accuracy. Most loads only have AC current, but some rare loads draw DC current, which can cause measurement errors. See our website for more information: http://www.ccontrolsys.com/w/DC_Current_and_Half-Wave_Rectified_Loads.

CTs can measure lower currents than they were designed for by passing the wire through the CT more than once. For example, to measure currents up to 1 amp with a 5 amp CT, loop the wire through the CT five times. The CT is now effectively a 1 amp CT instead of a 5 amp CT. The effective current rating of the CT is the labeled rating divided by the number of times that the wire passes through the CT.

If you are using the measurement phases of the WattNode (***ϕ*A**, ***ϕ*B**, and ***ϕ*C**) to measure different circuits (as with ***Option P3***), you can use CTs with different rated current on the different phases.

Current Crest Factor

The term “current crest factor” is used to describe the ratio of the peak current to the RMS current (the RMS current is the value reported by multimeters and the WattNode meter). Resistive loads like heaters and incandescent lights have nearly sinusoidal current waveforms with a crest factor near 1.4. Power factor corrected loads such as electronic lighting ballasts and computer power supplies typically have a crest factor of 1.4 to 1.5. Battery chargers, VFD motor controls, and other nonlinear loads can have current crest factors ranging from 2.0 to 3.0, and even higher.

High current crest factors are usually not an issue when metering whole building loads, but can be a concern when metering individual loads with high current crest factors. If the peak current is too high, the meter’s CT inputs can clip, causing inaccurate readings.

This means that when measuring loads with high current crest factors, you may want to be conservative in selecting the CT rated current. For example, if your load draws 10 amps RMS, but has a crest factor of 3.0, then the peak current is 30 amps. If you use a 15 amp CT, the meter will not be able to accurately measure the 30 amp peak current. Note: this is a limitation of the meter measurement circuitry, not the CT.

The following graph shows the maximum RMS current for accurate measurements as a function of the current waveform crest factor. The current is shown as a percentage of CT rated current. For example, if you have a 10 amp load with a crest factor of 2.0, the maximum CT current is approximately 85%. Eighty-five percent of 15 amps is 12.75, which is higher than 10 amps, so your measurements should be accurate. On the other hand, if you have a 40 amp load with a crest factor of 4.0, the maximum CT current is 42%. Forty-two percent of a 100 amp CT is 42 amps, so you would need a 100 amp CT to accurately measure this 40 amp load.

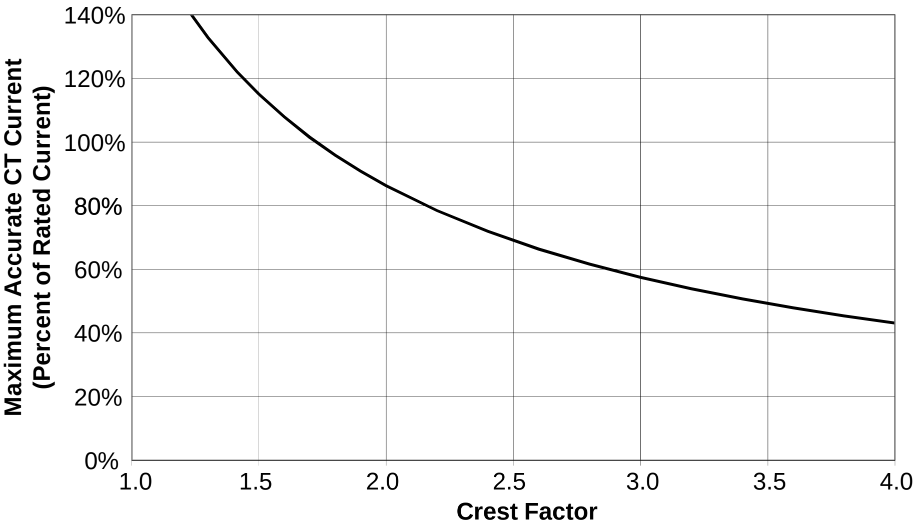


Figure 8: Maximum CT Current vs. Crest Factor

You frequently won't know the crest factor for your load. In this case, it's generally safe to assume the crest factor will fall in the 1.4 to 2.5 range and select CTs with a rated current roughly 150% of the expected RMS current. So if you expect to be measuring currents up to 30 amps, select a 50 amp CT.

Connecting Current Transformers

- Use only UL recognized current transformers (CTs) with built-in burden resistors that generate 0.33333 Vac (333.33 millivolts AC) at rated current. See **Current Transformers (p. 35)** for the maximum input current ratings.
- **Do not** use ratio (current output) CTs such as 1 amp or 5 amp output CTs: they will **destroy** the meter and present a shock hazard! These are commonly labelled with a ratio like 100:5.
- Find the arrow or label "THIS SIDE TOWARD SOURCE" on the CT and face toward the current source: generally the utility meter or the circuit breaker for branch circuits. If CTs are mounted backwards or with their white and black wires reversed the measured power will be negative. The diagnostic LEDs indicates negative power with flashing red LEDs.
- Be careful to match up the current transformers to the voltage phases being measured. Make sure the ***ϕ*A CT** is measuring the line voltage connected to ***ϕ*A**, and the same for phases B and C. Use the supplied colored labels or tape to identify the wires.
- To prevent magnetic interference, the CTs on different phases should be separated by 1 inch (25 mm). The line voltage conductors for each phase should be separated by at least 1 inch (25 mm) from each other and from neutral.
- For best accuracy, the CT opening should not be much larger than the conductor. If the CT opening is much larger, position the conductor in the center of the CT opening.
- Because CT signals are susceptible to interference, we recommend keeping the CT wires short and cutting off any excess length. It is generally better to install the meter near the line voltage conductors instead of extending the CT wires. However, you may extend the CT wires by 300 feet (100 m) or more by using shielded twisted-pair cable and by running the CT wires away from high current and line voltage conductors.
- OPTIONAL: if you see spurious readings on unused phases, jumper the unused CT inputs.

To connect CTs, pass the wire to be measured through the CT and connect the CT to the meter. **Always remove power before disconnecting any live wires.** Put the line conductors through the CTs as shown in the section **Electrical Service Types (p. 8)**. You may measure generated power by treating the generator as the source.

For solid-core CTs, disconnect the line voltage conductor to install it through the CT opening.

Split-core and bus-bar CTs can be opened for installation around a wire by puling the removable section straight away from the rest of the CT or unhooking the latch; it may require a strong pull. Some CT models include thumb-screws to secure the opening. The removable section may fit only one way, so match up the steel core pieces when closing the CT. If the CT seems to jam and will not close, the steel core pieces are probably not aligned correctly; **DO NOT FORCE** together. Instead, reposition or rock the removable portion until the CT closes without excessive force. A nylon cable tie can be secured around the CT to prevent inadvertent opening.

Some split-core CT models have flat mating surfaces. When installing this type of CT, make sure that mating surfaces are clean. Any debris between the mating surfaces will increase the gap, decreasing accuracy.

Next, connect the CT lead wires to the meter terminals labeled **ϕA CT**, **ϕB CT**, and **ϕC CT**. Route the twisted black and white wires from the CT to the meter. We recommend cutting off any excess length to reduce the risk of interference. Strip 1/4 inch (6 mm) of insulation off the ends of the CT leads and connect to the six position black screw terminal block. Connect each CT lead with the white wire aligned with the white dot on the label, and the black wire aligned with the black dot. Note the order in which the phases are connected, as the voltage phases **must** match the current phases for accurate power measurement.

Finally record the CT rated current as part of the installation record for each meter. If the conductors being measured are passed through the CTs more than once, then the recorded rated CT current is divided by the number of times that the conductor passes through the CT.

Circuit Protection

The WattNode meter is considered “permanently connected equipment”, because it does not use a conventional power cord that can be easily unplugged. **Permanently connected equipment must have overcurrent protection and be installed with a means to disconnect the equipment.**

- A switch, disconnect, or circuit breaker may be used to disconnect the meter and must be as close as practical to the meter. If a switch or disconnect is used, then there must also be a fuse or circuit breaker of appropriate rating protecting the meter.
- WattNode meters only draw 10-30 milliamps; CCS recommends using circuit breakers or fuses rated for between 0.5 amps and 20 amps and rated for the line voltages and the current interrupting rating required.
- The circuit breakers or fuses must protect the ungrounded supply conductors (the terminals labeled **ϕA**, **ϕB**, and **ϕC**). If neutral is also protected (this is rare), then the overcurrent protection device must interrupt neutral and the supply conductors simultaneously.
- Any switches or disconnects should have at least a 1 amp rating and must be rated for the line voltages.
- The circuit protection / disconnect system must meet IEC 60947-1 and IEC 60947-3, as well as all national and local electrical codes.
- The line voltage connections should be made with wire rated for use in a service panel or junction box with a voltage rating sufficient for the highest voltage present. CCS recommends 14 or 12 AWG (1.5 mm^2 or 2.5 mm^2) stranded wire, rated for 300 or 600 volts. Solid wire may be used, but must be routed carefully to avoid putting excessive stress on the screw terminal.
- The WattNode meter has an earth connection, which should be connected for maximum accuracy. However, this earth connection is not used for safety (protective) earthing.

Connecting Voltage Terminals

Always turn off or disconnect power before connecting the voltage inputs to the meter. Connect each phase voltage to the appropriate input on the green terminal block; also connect ground and neutral (if required).

The voltage inputs to the meter do not need to be powered from to the same branch circuit as the load being monitored. In other words, if you have a three-phase panel with a 100 A three-pole breaker powering a motor that you wish to monitor, you can power the meter (or several meters) from a separate 20 A three-pole breaker installed in the same, or even adjacent panel, so long as the load and voltage connections are supplied from the same electric service.

The green screw terminals handle wire up to 12 AWG (2.5 mm^2). Strip the wires to expose 1/4" (6 mm) of bare copper. When wiring the meter, do not put more than one wire under a screw. If you need to distribute power to other meters, use wire nuts or a power distribution block. The section **Electrical Service Types (p. 8)** shows the proper connections for the different meter models and electrical services. ***Verify that the voltage line phases match the CT phases.***

If there is any doubt that the meter voltage rating is correct for the circuit being measured, unplug the green terminal block (to protect the meter), turn on the power, and use a voltmeter to compare the voltages (probe the terminal block screws) to the values in the white box on the meter front label. After testing, plug in the terminal block, making sure that is pushed in all the way.

The WattNode meter is powered from the voltage inputs: ***ϕ*A** (phase A) to **N** (neutral) for wye "**-3Y**" models, or ***ϕ*A** to ***ϕ*B** for delta "**-3D**" models. If the meter is not receiving at least 80% of the nominal line voltage, it may stop operating. Since the meter consumes a small amount of power itself (typically 1-3 watts), you may wish to power the meter from a separate circuit or place the current transformers downstream of the meter, so its power consumption is not measured

For best accuracy, always connect the **N** (neutral) terminal on the meter. If you are using a delta meter and the circuit has no neutral, then jumper the earth ground to the **N** (neutral) terminal.

When power is first applied to the meter, check that the LEDs behave normally (see **Installation LED Diagnostics (p. 20)** below): if you see the LEDs flashing red-green-red-green, then disconnect the power immediately! This indicates the line voltage is too high for this model.

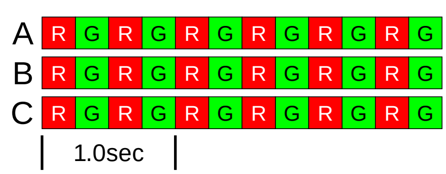


Figure 9: WattNode LED Overvoltage Warning

Connecting Pulse Outputs

- The outputs **P1**, **P2**, and **P3** should not be connected to negative voltages (except with ***Option SSR***), or to voltages greater than +60 Vdc.
- The recommended maximum current through the pulse output optoisolators is 5 mA, although they will generally switch 8-10 mA. If you need to switch higher currents, contact us about ***Option SSR*** (solid-state relay); see **Specifications** - **Option SSR Outputs (p. 33)**.
- The outputs are isolated (5000 Vac RMS) from dangerous voltages, so you can connect them with the meter powered. The outputs are also isolated from the meter's earth ground and neutral connections.
- If the output wiring is located near line voltage wiring, use wires or cables rated for the highest voltage present, generally 300V or 600V rated wire.
- If this cable will be in the presence of bare conductors, such as bus-bars, it should be double insulated or jacketed.
- When wiring over long distances, use shielded twisted-pair cable to prevent interference.

The pulse output channels are the collector and emitter of an optoisolator transistor (also called a photocoupler) controlled by the meter's pulse stream (see **Option SSR Outputs (p. 33)** for solid-state relay outputs). These outputs may be connected to most data monitoring devices that expect a contact closure or relay input: data loggers, energy management systems, etc. Most of these devices provide excitation voltage with internal pull-up resistors. If your device does not, the following schematic illustrates connecting pull-up resistors on all three optoisolator outputs with a pull-up voltage of 5 Vdc.

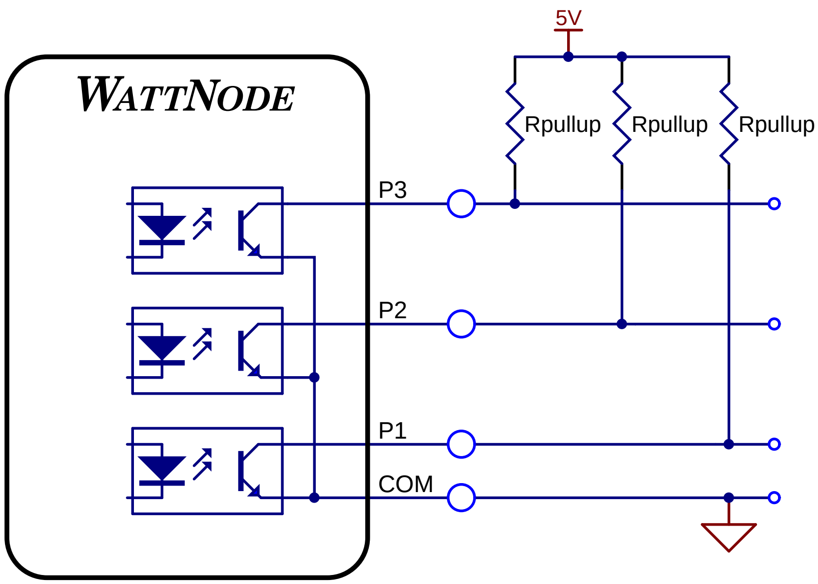


Figure 10: Optoisolator Outputs

The meter can have from one to three pulse output channels. All three output channels share the common **COM** or ground connection. Each output channel has its own positive output connection, labeled **P1**, **P2**, and **P3** (tied to the transistor collectors).

Output Assignments

The following table shows the pulse output channel assignments for the standard bidirectional output model and different options. See Manual Supplement MS-10 for details about ***Option PV***, and Manual Supplement MS-11 for details about ***Option DPO***.

WattNode Outputs	P1 Output	P2 Output	P3 Output
Standard: Bidirectional Outputs	Positive real energy (all phases)	Negative real energy (all phases)	Not used
Option P3: Per-Phase Outputs	Phase A positive real energy	Phase B positive real energy	Phase C positive real energy
Option PV: Photovoltaic	Phases A+B positive real energy	Phases A+B negative real energy	Phase C positive real energy
Option DPO: Dual Positive Outputs	Positive real energy (all phases)	Negative real energy (all phases)	Positive real energy (all phases)

Table 3: Pulse Output Assignments

Note: we use the terms "positive" and "negative", but other common terms are "production" and "consumption". You can wire the meter so that positive energy corresponds to either production or consumption, depending on your application.

Pull-Up Resistor Selection

For standard WattNode meters with the normal 4.00 Hz full-scale frequency, pull-up resistor values between 10kΩ and 100kΩ work well. You may use values of 1.0MΩ or higher to reduce power consumption for battery powered equipment. **Note:** pull-up resistor values of 1.0MΩ or higher will make the pulse output signal more susceptible to interference, so you may want to keep the wiring short, use shielded cable, and avoid running the pulse signal near AC wiring.

The following table lists pull-up resistor values (in ohms, kilo-ohms, and mega-ohms) to use with the pulse output channels, particularly if you have ordered a model with a pulse frequency different than 4.00 Hz. For each configuration, the table lists a recommended value, followed by minimum and maximum resistor values. These values typically result in a pulse waveform rise time (from 20% to 80% of the pull-up voltage) of less than 10% of the total pulse period. The fall time is roughly constant in the 2 to 10 microsecond range. Lower resistance will result in faster switching and increase the current flow. If your frequency isn't in the table, use the next higher frequency or interpolate between two values.

Full-Scale Pulse Frequency	Pull-up to 3.0 Vdc Recommended (Min-Max)	Pull-up to 5.0 Vdc Recommended (Min-Max)	Pull-up to 12 Vdc Recommended (Min-Max)	Pull-up to 24 Vdc Recommended (Min-Max)
1 Hz	470kΩ (600Ω-4.7M)	470kΩ (1.0k-5.6M)	470kΩ (2.4k-7.5M)	1.0MΩ (4.7k-9.1M)
4 Hz	**100kΩ (600Ω-1.2M)**	**100kΩ (1.0k-1.6M)**	**100kΩ (2.4k-2.2M)**	**200kΩ (4.7k-3.0M)**
10 Hz	47kΩ (600Ω-470k)	47kΩ (1.0k-620k)	47kΩ (2.4k-910k)	100kΩ (4.7k-1.3M)
50 Hz	10kΩ (600Ω-91k)	10kΩ (1.0k-130k)	20kΩ (2.4k-200k)	47kΩ (4.7k-270k)
100 Hz	4.7kΩ (600Ω-47k)	4.7kΩ (1.0k-62k)	10kΩ (2.4k-100k)	20kΩ (4.7k-130k)
200 Hz	2.0kΩ (600Ω-24k)	2.0kΩ (1.0k-33k)	4.7kΩ (2.4k-47k)	10kΩ (4.7k-68k)
600 Hz	2.0kΩ (600Ω-8.2k)	2.0kΩ (1.0k-12k)	4.7kΩ (2.4k-16k)	10kΩ (4.7k-22k)

Table 4: Recommended Pulse Output Pull-up Resistors

When the optoisolator is on (conducting), there is a small voltage drop between the common and output terminals, typically 0.1 - 0.4 volts, called the saturation voltage. This voltage depends on the current flow through the optoisolator (see **Specifications - Optoisolator Outputs (p. 32)** below for details). To compute the current flow through the optoisolator, use the following approximate equation:

- ***Vpullup*** - The supply voltage for the pull-up resistor (DC volts).
- ***Rpullup*** - The pull-up resistor resistance (ohms).
- ***Iopto*** - The approximate current (amps) through the optoisolator when it is on (conducting).

$$Iopto = Vpullup / Rpullup$$

Installation Summary

1) Mount the WattNode meter.
2) Turn off power before installing solid-core (non-opening) CTs or making voltage connections.
3) Mount the CTs around the line voltage conductors being measured. Take care to orient the CTs facing the source of power.
4) Connect the twisted white and black wires from the CT to the six position black terminal block on the meter, matching the wire colors to the white and black dots on the front label.
5) Connect the voltage wires including ground and neutral (if present) to the green terminal block, and check that the current (CT) phases match the voltage measurement phases.
6) Connect the pulse output terminals of the meter to the monitoring equipment.
7) Apply power to the meter.
8) Verify that the LEDs light correctly and don't indicate an error condition.

Installation LED Diagnostics

The WattNode meter includes multi-color power diagnostic LEDs for each phase to help verify correct operation and diagnose incorrect wiring. The LEDs are marked “Status” on the label. The following diagrams and descriptions explain the various LED patterns and their meanings. The A, B, and C on the left side indicate the phase of the LEDs. Values like “1.0sec” and “3.0sec” indicate the time the LEDs are lit in seconds. In the diagrams, sometimes the colors are abbreviated: R = red, G or Grn = green, Y = yellow.

Normal Startup

On initial power-up, the LEDs will all light up in a red, yellow, green sequence. After this startup sequence, the LEDs will show the status, such as **Normal Operation** below.

A	Red	Yellow	Green
B	Red	Yellow	Green
C	Red	Yellow	Green
	1.0sec	1.0sec	1.0sec

Normal Operation

During normal operation, when positive power is measured on a phase, the LED for that phase will flash green. Typical flash rates are shown below.

Green	Off	Green	Off	Green	Off

Percent of Full-Scale Power	LED Flash Rate	Flashes in 10 Seconds
100%	5.0 Hz	50
50%	3.6 Hz	36
25%	2.5 Hz	25
10%	1.6 Hz	16
5%	1.1 Hz	11
1% (and lower)	0.5 Hz	5

Table 5: LED Flash Rates vs. Power

Zero Power

Green

For each phase, if line Vac is present, but the measured power is below the minimum that the meter will measure (see **Specifications - Measurement - Creep Limit**), the meter will display solid green for that phase.

Inactive Phase

If the meter detects no power and line voltage below 20% of nominal, it will turn off the LED for the phase.

Off

Negative Power

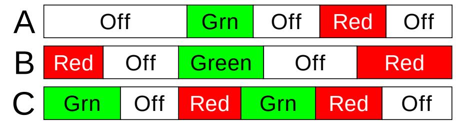
If one or more of the phase LEDs are flashing red, it indicates negative power (power flowing into the grid) on those phases. The rate of flashing indicates magnitude of negative power (see **Table 5** above). This can happen for the following reasons:

A	Red	Off	Red	Off	Red	Off
B	Off	Red	Off	Red	Off	Red
C	Red	Off	Red	Off	Red	Off

- This is a bidirectional power measurement application, such as a photovoltaic system, where negative power occurs whenever you generate more power than you consume.
- The current transformer (CT) for this phase was installed backwards on the current carrying wire or the white and black wires for the CT were reversed at the meter. This can be solved by flipping the CT on the wire or swapping the white and black wires at the meter.
- In some cases, this can also occur if the CT wires are connected to the wrong inputs, such as if the CT wires for phases B and C are swapped.

Note: if all three LEDs are flashing red and they always turn on and off together, like the diagram for **Low Line Voltage** below, then the meter is experiencing an error or low line voltage, not negative power.

Erratic Flashing



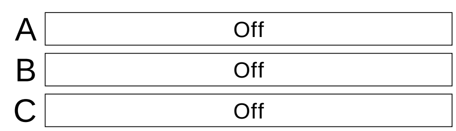
If the LEDs are flashing slowly and erratically, sometimes green, sometimes red, this generally indicates one of the following:

- Earth ground is not connected to the meter (the top connection on the green screw terminal).
- Voltage is connected for a phase, but the current transformer is not connected, or the CT has a loose connection.
- In some cases, particularly for a circuit with no load, this may be due to electrical noise. This is not harmful and can generally be disregarded, provided that you are not seeing substantial measured power when there shouldn't be any. Try turning on the load to see if the erratic flashing stops.

To fix this, try the following:

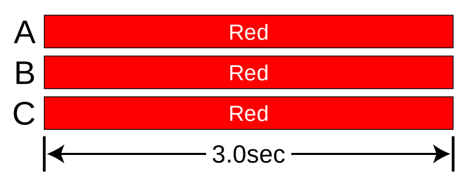
- Make sure earth ground is connected.
- If there are unused current transformer inputs, install a shorting jumper for each unused CT (a short length of wire connected between the white and black dots marked on the label).
- If there are unused voltage inputs (on the green screw terminal), connect them to neutral (if present) or earth ground (if neutral isn't available).
- If you suspect noise may be the problem, try moving the meter away from the source of noise. Also try to keep the CT wires as short as possible and cut off excess wire.

Meter Not Operating



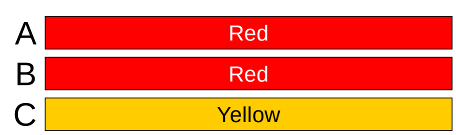
It should not be possible for all three LEDs to stay off when the meter is powered, because the phase powering the meter will have line voltage present. Therefore, if all LEDs are off, the meter is either not receiving sufficient line voltage to operate, or is malfunctioning and needs to be returned for service. Verify that the voltage on the Vac screw terminals is within ±20% of the nominal operating voltages printed in the white rectangle on the front label.

Meter Error



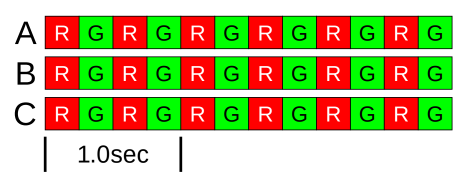
If the meter experiences an internal error, it will light all LEDs red for three seconds (or longer). If you see this happen repeatedly, return the meter for service.

Bad Calibration



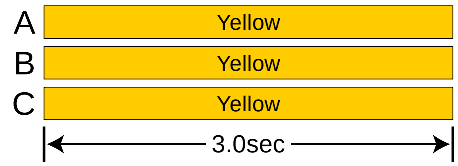
This indicates that the meter has detected bad calibration data and must be returned for service.

Line Voltage Too High



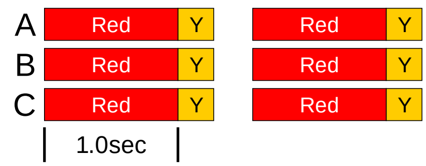
Whenever the meter detects line voltages over 125% of normal for one or more phases, it will display a fast red/green flashing for the affected phases. This is harmless if it occurs due a momentary surge, but if the line voltage is high continuously, **the power supply may fail. If you see continuous over-voltage flashing, disconnect the meter immediately!** Check that the model and voltage rating is correct for the electrical service.

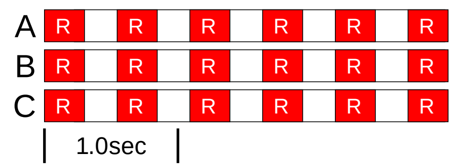
Bad Line Frequency



If the meter detects a power line frequency below 45 Hz or above 70 Hz, it will light all the LEDs yellow for at least three seconds. The LEDs will stay yellow until the line frequency returns to normal. During this time, the meter should continue to accurately measure power. This can occur in the presence of extremely high noise, such as if the meter is too close to an unfiltered variable frequency drive.

Low Line Voltage





These LED patterns occur if the line voltage is too low for the meter to operate correctly and the meter reboots repeatedly. The pattern will be synchronized on all three LEDs. Verify that the voltage on the Vac screw terminals is not more than 20% lower than the nominal operating voltages printed in the white rectangle on the front label. If the voltages are in the normal range and the meter continues to display one of these patterns, return it for service.

Measurement Troubleshooting

If the WattNode meter does not appear to be operating correctly or generating expected pulses, start by checking the diagnostic LEDs as described in the previous section **Installation LED Diagnostics (p. 20)**. Then double check the installation instructions. If there are still problems, check the following.

No Pulses

- Make sure the load is turned on.
- If the LEDs are flashing green, then the meter is measuring positive power and should output pulses on **P1**, so there may be something wrong with the pulse output connection or you may need a pull-up resistor; see **Connecting Pulse Outputs (p. 17)**.
- If the LEDs on one or more phases are flashing red, then the total power may be negative, in which case the meter won't generate positive energy pulses. If you have a bidirectional model, you can check for negative energy pulses on the **P2** output. If this is the case, check that the line phases match the CT phases, that all the CTs face the source of power, and that the CT white and black wires are connected correctly.
- If all the LEDs are solid green (or off), then the measured power is below the creep limit (1/1500th of full-scale) and the meter will not generate any pulses. See **Specifications - Creep Limit (p. 32)**.
- If the LEDs are flashing green slowly, the power may be very low. A WattNode meter with a nominal output frequency of 4.00 Hz can have a pulse period of several minutes at very low power levels.
- If all the LEDs are off, then the meter does not have sufficient line voltage to operate, or has malfunctioned. Use a DMM (multimeter) to verify that the voltage on the Vac screw terminals is within -20%, +15% of the nominal operating voltage.

Incorrect Power or Energy Readings.

This can be caused by any of the following:

- An incorrect estimate of expected power or energy readings. If possible, try to verify the actual energy, power, or current with a handheld power meter or current clamp.

- Incorrect scale factors to convert from pulses to energy and power. This is commonly caused by using the normal scale factors with an ***Option P3*** meter or selecting the wrong row of column from the tables.
- Some pulse counting equipment (data loggers, etc.) counts both rising and falling edges as pulses, resulting in a count that is double the intended value. This can normally be corrected by reconfiguring the device or dividing the scale factor by 2.0.
- Some pulse monitoring devices cannot handle fast pulse rates. If the pulses occur too close together, some may be missed by the monitoring device. Check the specifications of your monitoring device or contact CCS support for assistance.
- The CTs are not installed on the correct line phases. Verify that the CT phasing matches the line Vac inputs.
- The measured current exceeds the CT rating. This can saturate CT or the WattNode meter input circuitry, resulting in lower than expected readings. If possible, use a current clamp to measure the current and make sure it is below the CT rated amps.
- The measured current is too small. Most current transformers are only specified to meet their accuracy from 10% to 100% of rated current. In practice, most CTs work reasonably well down to 1% of rated current. Very low currents may not register properly, resulting in low power or no power reported.
- Interference from a variable frequency or variable speed drive: VFD, VSD, inverter, or the like. Generally, these drives should not interfere with the meter, but if they are in very close proximity, or if the CT leads are long, interference can occur. Try moving the meter at least three feet (one meter) away from any VFDs. Use short CT leads if possible. **NEVER** connect the meter downstream of a VFD: the varying line frequency and extreme noise will cause problems!
- The CTs may be malfunctioning. If possible, use a current clamp to verify the current, then use a DMM (multimeter) to measure the AC voltage between the white and black wires from the CT (leave them connected to the meter during this test). At rated current, the CT output voltage should equal 0.333 Vac (333 millivolts AC). At lower currents, the voltage should scale linearly, so at 20% of rated current, the output voltage should be 0.20 * 0.333 = 0.0666 Vac (66.6 millivolts AC).
- The meter is not functioning correctly: if possible, swap the meter for another unit of the same model.

Operating Instructions

Pulse Outputs

The WattNode meter generates pulse outputs using one or more optoisolators (also called photocouplers). These provide 5000 Vac of isolation using an LED and a photo-transistor. This allows the meter to be interfaced to monitoring or data logging hardware without concerns about interference, ground loops, shock hazard, etc.

Depending on the options selected, the Pulse WattNode meter can generate full-scale pulses at output frequencies ranging from less than 1 Hz to 600 Hz. The standard full-scale pulse output frequency is 4.00 Hz. The standard model provides two pulse streams for measuring bidirectional power. With ***Option P3***, there are three pulse channels for independently measuring each phase or three single-phase circuits.

The pulse outputs are approximately square-waves, with equal on and off periods. The frequency of pulses is proportional to the measured power. When the measured power is constant, the pulse frequency is constant and the output is an exact square-wave. If the power is increasing or decreasing, the output waveform will not be a perfect square-wave as the on and off periods are getting longer or shorter. If you need a fixed or minimum pulse duration (closed period), see Manual Supplement MS-17: Option PW (Pulse Width).

We define a "pulse" as a full cycle including both an Open→Closed and an Closed→Open transition. You can choose either a rising or falling edge to start a pulse; the end of the pulse will be the next matching edge. Some monitoring equipment or data loggers can be configured to count ***both*** rising and falling edges: if your equipment is configured this way, you will count twice as many pulses as expected. This can normally be corrected by reconfiguring the equipment or adjusting the scale factors by a factor of 2.

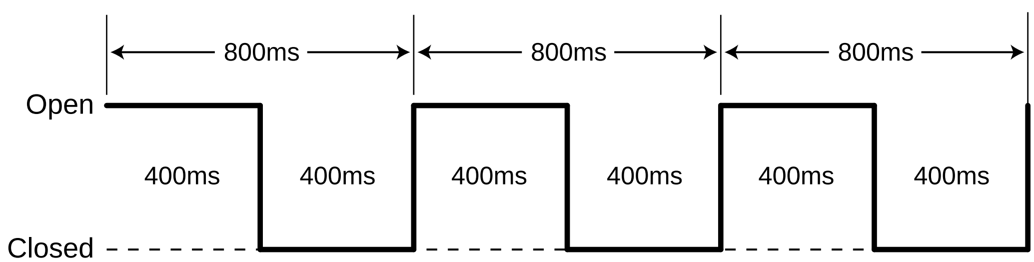


Figure 11: Output Pulses for Steady Power

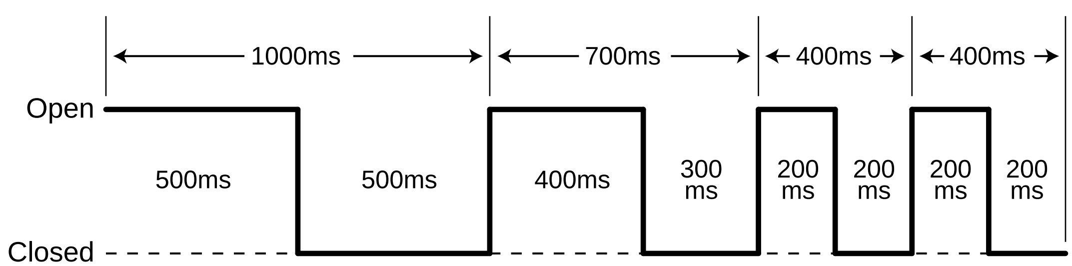


Figure 12: Output Pulses for Increasing Power

See **Connecting Pulse Outputs (p. 17)** and **Specifications - Pulse Outputs (p. 32)** for more information.

Power and Energy Computation

Every pulse from the meter corresponds to a fixed amount of energy. Power (watts) is energy divided by time, which can be measured as pulses per second (or pulses per hour). The following scale factor tables and equations convert from pulses to energy (watt-hours or kilowatt-hours) for different models.

If you have ordered a custom full-scale pulse output frequency, then see the **Power and Energy Equations** section below. For ***Option PV (Photovoltaic)***, see Manual Supplement MS-10: Option PV for scale factors.

Scale Factors - Standard Bidirectional Outputs (and Option DPO)

The following table provides scale factors for standard bidirectional output models with a full-scale pulse output frequency of 4.00 Hz. This table also works for 4.00 Hz models with ***Option DPO***. Equations to compute power and energy follow the scale factor tables.

CT Size (amps)	Watt-hours per pulse (*WHpP*)				Pulses Per kilowatt-hour (*PpKWH*)			
	3Y-208 3D-240	3Y-400 3D-400	3Y-480 3D-480	3Y-600	3Y-208 3D-240	3Y-400 3D-400	3Y-480 3D-480	3Y-600
5	0.125	0.2396	0.2885	0.3615	8000.00	4173.91	3465.70	2766.57
15	0.375	0.7188	0.8656	1.0844	2666.67	1391.30	1155.24	922.190
20	0.500	0.9583	1.1542	1.4458	2000.00	1043.48	866.426	691.643
30	0.750	1.4375	1.7313	2.1688	1333.33	695.652	577.617	461.095
50	1.250	2.3958	2.8854	3.6146	800.000	417.391	346.570	276.657
60	1.500	2.8750	3.4625	4.3375	666.667	347.826	288.809	230.548
70	1.750	3.3542	4.0396	5.0604	571.429	298.137	247.550	197.612
100	2.500	4.7917	5.7708	7.2292	400.000	208.696	173.285	138.329
150	3.750	7.1875	8.6563	10.844	266.667	139.130	115.523	92.219
200	5.000	9.5833	11.542	14.458	200.000	104.348	86.643	69.164
250	6.250	11.979	14.427	18.073	160.000	83.478	69.314	55.331
300	7.500	14.375	17.313	21.688	133.333	69.565	57.762	46.110
400	10.000	19.167	23.083	28.917	100.000	52.174	43.321	34.582
600	15.000	28.750	34.625	43.375	66.667	34.783	28.881	23.055
800	20.000	38.333	46.167	57.833	50.000	26.087	21.661	17.291
1000	25.000	47.917	57.708	72.292	40.000	20.870	17.329	13.833
1200	30.000	57.500	69.250	86.750	33.333	17.391	14.440	11.527
1500	37.500	71.875	86.563	108.44	26.667	13.913	11.552	9.2219
2000	50.000	95.833	115.42	144.58	20.000	10.435	8.6643	6.9164
3000	75.000	143.75	173.13	216.88	13.333	6.9565	5.7762	4.6110
any	$\frac{CtAmps}{40}$	$\frac{CtAmps}{20.87}$	$\frac{CtAmps}{17.329}$	$\frac{CtAmps}{13.833}$	$\frac{40,000}{CtAmps}$	$\frac{20,870}{CtAmps}$	$\frac{17,329}{CtAmps}$	$\frac{13,833}{CtAmps}$

Table 6: Scale Factors - Bidirectional Outputs

Contact CCS for scale factors for models with full-scale pulse output frequencies other than 4.00 Hz.

Scale Factors - Option P3: Per-Phase Outputs

The following table provides scale factors for ***Option P3*** models with a full-scale pulse output frequencies of 4.00 Hz for each phase. Note: with ***Option P3***, different phases can use different CTs with different rated currents.

WARNING: Only use this table if you have ***Option P3*** (Per-Phase Outputs)!

CT Size (amps)	Watt-hours per pulse (*WHpP*)				Pulses Per kilowatt-hour (PpKWH)			
	3Y-208 3D-240	3Y-400 3D-400	3Y-480 3D-480	3Y-600	3Y-208 3D-240	3Y-400 3D-400	3Y-480 3D-480	3Y-600
5	0.04167	0.07986	0.09618	0.12049	24000.0	12521.7	10397.1	8299.71
15	0.1250	0.2396	0.2885	0.3615	8000.00	4173.91	3465.70	2766.57
20	0.1667	0.3194	0.3847	0.4819	6000.00	3130.43	2599.28	2074.93
30	0.2500	0.4792	0.5771	0.7229	4000.00	2086.96	1732.85	1383.29
50	0.4167	0.7986	0.9618	1.2049	2400.00	1252.17	1039.71	829.971
60	0.5000	0.9583	1.1542	1.4458	2000.00	1043.48	866.426	691.643
70	0.5833	1.1181	1.3465	1.6868	1714.29	894.410	742.651	592.837
100	0.8333	1.5972	1.9236	2.4097	1200.00	626.087	519.856	414.986
150	1.2500	2.3958	2.8854	3.6146	800.000	417.391	346.570	276.657
200	1.6667	3.1944	3.8472	4.8194	600.000	313.043	259.928	207.493
250	2.0833	3.9931	4.8090	6.0243	480.000	250.435	207.942	165.994
300	2.5000	4.7917	5.7708	7.2292	400.000	208.696	173.285	138.329
400	3.3333	6.3889	7.6944	9.6389	300.000	156.522	129.964	103.746
600	5.0000	9.5833	11.542	14.458	200.000	104.348	86.643	69.164
800	6.6667	12.778	15.389	19.278	150.000	78.261	64.982	51.873
1000	8.3333	15.972	19.236	24.097	120.000	62.609	51.986	41.499
1200	10.000	19.167	23.083	28.917	100.000	52.174	43.321	34.582
1500	12.500	23.958	28.854	36.146	80.000	41.739	34.657	27.666
2000	16.667	31.944	38.472	48.194	60.000	31.304	25.993	20.749
3000	25.000	47.917	57.708	72.292	40.000	20.870	17.329	13.833
any	$\frac{CtAmps}{120.00}$	$\frac{CtAmps}{62.609}$	$\frac{CtAmps}{51.986}$	$\frac{CtAmps}{41.499}$	$\frac{120{,}000}{CtAmps}$	$\frac{62{,}609}{CtAmps}$	$\frac{51{,}986}{CtAmps}$	$\frac{41{,}499}{CtAmps}$

Table 7: Scale Factors - Per-Phase Outputs *(Option P3)*

Scale Factor Equations

Using the "Watt-hours per pulse" ***WHpP*** value from the table above for your model and current transformer, you can compute energy and power as follows:

- ***PulseCount*** - This is the count of pulses, used to compute energy. You can use the count of pulses over specified periods of time (like a month) to measure the energy for that period of time.
- ***PulseFreq*** - This is the measured pulse frequency (Hertz) out of the meter. This can also be computed by counting the number of pulses in a fixed period of time and then dividing by the number of seconds in that time period. For example, if you count 720 pulses in five minutes (300 seconds), then ***PulseFreq*** = 720 / 300 = 2.40 Hz.

$$Energy\ (watt\text{-}hours) = WHpP \cdot PulseCount$$

$$Power\ (watts) = WHpP \cdot 3600 \cdot PulseFreq$$

To convert these values to kilowatt-hours and kilowatts, divide by 1000.

Using the “Pulses Per kilowatt-hour” ***PpKWH*** value from the table above for your model and current transformer, you can compute energy and power as follows (multiply by 1000 to convert kilowatts to watts):

$$\text{Energy (kilowatt-hours)} = PulseCount / PpKWH$$

$$\text{Power (kilowatts)} = 3600 \cdot PulseFreq / PpKWH$$

Power and Energy Equations

This section shows how to compute power and energy from pulses for any full-scale pulse output frequency. The power is proportional to the pulse frequency, while the energy is proportional to the count of pulses.

For these calculations, we use the following variables:

- ***NVac*** - This is the **nominal** line voltage (phase to neutral) of the WattNode model. For delta model, this is a virtual voltage, since there may not be a neutral connection. Note: this is **not** the actual measured voltage.
- ***PpPO*** - “Phases per Pulse Output”. This is the number of meter voltage phases associated with a pulse output channel. This may be different than the number of phases you are monitoring.
  - ***Standard*** and ***Option DPO*** (Dual Positive Outputs): ***PpPO*** = 3
  - ***Option P3*** (Per-Phase Outputs): ***PpPO*** = 1
  - ***Option PV*** (Photovoltaic): ***PpPO*** = 2 for outputs **P1** and **P2**, ***PpPO*** = 1 for output **P3**
- ***CtAmps*** - This is the current transformer (CT) rated amps. Note: If the conductors being measured are passed through the CTs more than once, then ***CtAmps*** is the rated CT current divided by the number of times that the conductor passes through the CT.
- ***FSHz*** - This is the full-scale pulse frequency of the meter. It is 4.00 Hz, unless the meter was ordered with ***Option Hz=xxx*** (where ***xxx*** specifies the full-scale pulse frequency) or ***Option Kh***.
- ***PulseCount*** - This is the measured pulse count, used to compute energy. You can use the count of pulses over specified periods of time (such as a month) to measure the energy for that period of time.
- ***PulseFreq*** - This is the measured pulse frequency from one of the pulse channels (**P1**, **P2**, or **P3**). This can be computed by counting the number of pulses in a fixed period of time and then dividing by the number of seconds in that time period. For example, if you count 720 pulses in five minutes (300 seconds), then ***PulseFreq*** = 720 / 300 = 2.40 Hz.

The values of the constant parameters are in the following table.

WattNode Models	NVac	Standard FSHz Values
WNB-3Y-208-P	120	4.00 Hz
WNB-3Y-400-P	230	4.00 Hz
WNB-3Y-480-P	277	4.00 Hz
WNB-3Y-600-P	347	4.00 Hz
WNB-3D-240-P	120*	4.00 Hz
WNB-3D-400-P	230*	4.00 Hz
WNB-3D-480-P	277*	4.00 Hz

**Note: these are “virtual” line-to-neutral voltages used for delta model power and energy computations.*

Table 8: Power and Energy Parameters

Watt-Hours per Pulse

$$WHpP = \frac{PpPO \cdot NVac \cdot CtAmps}{FSHz \cdot 3600}$$

Watt-Hours per Pulse per CT Rated Amp

There is an alternate way of computing the energy reported by a meter using the variable ***WHpPpA*** (watt-hours per pulse per CT rated amp). If you multiply the ***WHpPpA*** by the amp rating of your CTs, the result will be the watt-hours measured each time the meter generates a pulse.

$$EnergyPerPulse\ (WH) = WHpPpA \cdot CtAmps$$

The standard ***WHpPpA*** values are listed in the following table. These only apply for models with a 4.00 Hz full-scale pulse frequency.

WattNode Models	Watt-Hours per Pulse per CT Rated Amp (FSHz = 4.00)	
	Standard and ***Option DPO*** Outputs	***Option P3***: Per-Phase Outputs
WNB-3Y-208-P	0.02500	0.008333
WNB-3Y-400-P	0.04792	0.01597
WNB-3Y-480-P	0.05771	0.01924
WNB-3Y-600-P	0.07229	0.02410
WNB-3D-240-P	0.02500	0.008333
WNB-3D-400-P	0.04792	0.01597
WNB-3D-480-P	0.05771	0.01924

Table 9: Watt-Hours per Pulse per CT Rated Amp

For example: a WNB-3Y-208-P with a full-scale pulse frequency of 4.00 Hz has a ***WHpPpA*** value of 0.0250. With 15 amp CTs, it will output one pulse for every 0.375 watt-hours.

$$(0.025) \cdot (15.0 \text{ amps}) = 0.375 \text{ watt-hours}$$

It is easy to use the ***WHpPpA*** value to compute energy:

$$Energy\ (Wh) = WHpPpA \cdot CtAmps \cdot PulseCount$$

For non-standard models, you can compute ***WHpPpA*** as follows:

$$WHpPpA = \frac{PpPO \cdot NVac}{FSHz \cdot 3600}$$

Energy Equation

The following equation computes the energy (watt-hours) associated with a pulse output channel. By using the ***PulseCount*** for different periods of time (day, week, month, etc.), you can measure the energy over different time periods. You can convert this to kilowatt-hours by dividing by 1000. The 3600 term in the denominator converts from watt-seconds to watt-hours. Note: use ***NVac*** value from **Table 8** above.

$$Energy\ (WH) = \frac{NVac \cdot PpPO \cdot CtAmps \cdot PulseCount}{FSHz \cdot 3600}$$

Pulses per Watt-Hour

$$PpWH = \frac{FSHz \cdot 3600}{NVac \cdot PpPO \cdot CtAmps}$$

Pulses Per Kilowatt-Hour

$$PpKWH = \frac{FSHz \cdot 3600 \cdot 1000}{NVac \cdot PpPO \cdot CtAmps}$$

Full-Scale Power Equation

The following equation computes the nominal full-scale power associated with a pulse output channel. For bidirectional output models, this is the full-scale power for all phases together. For per-phase output models, this is the full-scale power for a single phase. Note: use ***NVac*** value from **Table 8: Power and Energy Parameters** above.

$$Full\text{-}Scale\ Power\ (W) = NVac \cdot PpPO \cdot CtAmps$$

Power Equation

The following equation computes the power associated with a pulse output. The ***PulseFreq*** value may be measured or averaged over different time periods to compute the average power (also called demand). Note: use ***NVac*** value from **Table 8** above.

$$Power\ (W) = \frac{NVac \cdot PpPO \cdot CtAmps \cdot PulseFreq}{FSHz}$$

Maintenance and Repair

The WattNode Pulse meter requires no maintenance. There are no user serviceable or replaceable parts except the pluggable screw terminals.

The WattNode meter should not normally need to be cleaned, but if cleaning is desired, power must be disconnected first and a dry or damp cloth or brush should be used.

The WattNode meter is not user serviceable. In the event of any failure, the meter must be returned for service (contact CCS for an RMA). In the case of a new installation, follow the diagnostic and troubleshooting instructions before returning the meter for service, to ensure that the problem is not connection related.

Specifications

Models

Model	Nominal Vac Line-to-Neutral	Nominal Vac Line-to-Line	Phases	Wires
WNB-3Y-208-P	120	208–240	3	4
WNB-3Y-400-P	230	400	3	4
WNB-3Y-480-P	277	480	3	4
WNB-3Y-600-P	347	600	3	4
WNB-3D-240-P	120*	208–240	3	3–4
WNB-3D-400-P	230*	400	3	3–4
WNB-3D-480-P	277*	480	3	3–4

**Note: the delta models have an optional neutral connection that may be used for measuring wye circuits. In the absence of neutral, voltages are measured with respect to ground. Delta WattNode models use the phase A and phase B connections for power.*

Table 10: WattNode Models

Model Options

Any of these models are available with the following options:

- **Bidirectional Outputs** - *(this is the standard model)* This model has two pulse output channels. **P1** generates pulses in proportion to the total real positive energy, while **P2** generates pulses in proportion to the total real negative energy. The individual phase energies are all added together every 200 ms. If the result is positive, it is accumulated for the **P1** output; if negative, it is accumulated for the **P2** output. If one phase has negative power (-100 W), while the other two phases have positive power (+100 W each), the negative phase will subtract from the positive phases, resulting in a net of 100 W, causing pulses on **P1**, but no pulses on **P2**. There will only be pulses on **P2** if the sum of all three phases is negative.
- ***Option P3*: Per-Phase Outputs** - Models with this option have three pulse output channels: **P1**, **P2**, and **P3**. Each generates pulses in proportion to the real positive energy measured on one phase (phases A, B, and C respectively).
- ***Option DPO*: Dual Positive Outputs** - This option is like the standard model with bidirectional outputs, but with the addition of the **P3** output channel. The **P3** channel indicates positive real energy, just like the **P1** channel. This is useful when the meter needs to be connected to two different devices, such as a display and a data logger. See Manual Supplement MS-11: Option DPO (Dual Positive Outputs) for details.
- ***Option PV*: Photovoltaic** - The photovoltaic option measures residential PV systems. It allows one WattNode meter to measure the bidirectional total house energy, and the PV (or wind) generated energy. See Manual Supplement MS-10: Option PV (Photovoltaic) for details.
- ***Option Hz*: Custom Pulse Output Frequency** - WattNode meters are available with custom full-scale pulse output frequencies ranging from 0.01 Hz to 600 Hz (150 Hz maximum for ***Options P3, DPO,*** and ***PV***). For custom frequencies, specify ***Option Hz=nnn***, where ***nnn*** is the desired full-scale frequency. To specify different frequencies for **P1**, **P2**, and **P3**, use ***Option Hz=rrr/sss/ttt***, where **P1** frequency = ***rrr***, **P2** frequency = ***sss***, **P3** frequency = ***ttt***.
- ***Option SSR*: Solid State Relay Output** - Replaces the standard optoisolator outputs with solid state relays capable of switching 500 mA at up to 40 Vac or ±60 Vdc. See **Option SSR Outputs** below for details.
- ***Option TVS=24*** - Install 24 V bidirectional TVS protection diodes across P1, P2, and P3 outputs. Used with ***Option SSR*** when driving 12 Vdc electromechanical counters to protect the solid-state relays from the inductive kickback of the counter.

- ***Option PW: Pulse Width*** - This specifies the pulse **ON** (closed or conducting) period in milliseconds. For example, ***Opt PW=100*** configures 100 millisecond pulse **ON** periods. See Manual Supplement MS-17: Option PW (Pulse Width) for details.
- ***Option Kh: Watt-hour Constant*** - This specifies the watt-hour constant, or the number of watt-hours that must accumulate for each pulse generated by the meter. Each pulse includes an **ON** (conducting) and **OFF** period. The number of watt-hours may be small, even less than one, or large. For example, ***Opt Kh=1000*** specifies one pulse per 1000 watt-hours (one pulse per kilowatt-hour). See http://www.ccontrolsys.com/w/Option_Kh.
- ***Option CT: Current Transformer Rated Amps*** - This specifies the rated amps of the attached current transformers. This is only used in conjunction with ***Option Kh***. It may be specified as ***Opt CT=xxx*** or ***Opt CT=xxx/yyy/zzz*** if there are CTs with different rated amps on different phases. See http://www.ccontrolsys.com/w/WattNode_Pulse_-_Option_CT_-_CT_Rated_Amps.

Accuracy

The following accuracy specifications do not include errors caused by the current transformer accuracy or phase angle errors. “Rated current” is the current that generates a CT output voltage of 0.33333 Vac.

Condition 1 - Normal Operation

Line voltage: -20% to +15% of nominal

Power factor: 1.0

Frequency: 48 - 62 Hz

Ambient Temperature: 25°C

CT Current: 5% - 100% of rated current

Accuracy: ±0.5% of reading

Condition 2 - Low CT Current

All conditions the same as Condition 1 except:

CT Current: 1% - 5% of rated current

Accuracy: ±1.0% of reading

Condition 3 – Very Low CT Current

All conditions the same as Condition 1 except:

CT Current: 0.2% - 1% of rated current

Accuracy: ±3.0% of reading

Condition 4 - High CT Current

All conditions the same as Condition 1 except:

CT Current: 100% - 120% of rated current

Accuracy: ±1.0% of reading

Condition 5 - Low Power Factor

All conditions the same as Condition 1 except:

Power factor: 0.5 (±60 degree phase shift between current and voltage)

Additional Error: ±0.5% of reading

Condition 6 - Temperature Variation

All conditions the same as Condition 1 except:

Ambient Temperature: -30°C to +55°C

Additional Error: ±0.75% of reading

*Note: **Option PV** WattNode models may not meet these accuracy specifications for the* **P3** *output channel when measuring a two-phase inverter or multiple inverters.*

Measurement

Creep Limit: 0.067% (1/1500th) of full-scale. Whenever the apparent power (a combination of the real and reactive power values) for a phase drops below the creep limit, the output power (real) for the phase will be forced to zero. Also, if the line voltage for a phase drops below 20% of nominal Vac, the output power for the phase will be set to zero. These limits prevent spurious pulses due to measurement noise.

Update Rate: ~200 milliseconds. Internally, the consumed energy is measured at this rate and used to update the pulse output rate.

Start-Up Time: approximately 500 milliseconds. The meter starts measuring power and generating pulses 500 milliseconds after AC voltage is applied

Current Transformer Phase Angle Correction: 1.0 degree leading. Current transformers (CTs) typically have a leading phase angle error ranging from 0.2 degrees to 2.5 degrees. The WattNode meter is normally programmed to correct for a 1.0 degree phase lead to provide good accuracy with typical CTs.

Over-Voltage Limit: 125% of nominal Vac. If the line voltage for one or more phases exceeds this limit, the status LEDs for these phases will flash alternating red-green as a warning. Extended over-voltage operation can damage the meter and void the warranty. See **Line Voltage Too High (p. 21)**.

Over-Current Limit: 120% of rated current. Exceeding 120% of rated current will not harm the WattNode meter but the current and power will not be measured accurately.

Pulse Outputs

Factory Programmable Full-Scale Pulse Frequencies:

- **Standard (All Models):** 4.00 Hz
- **Custom (Bidirectional Output Models):** 0.01 Hz to 600 Hz
- **Custom (Option P3, Option PV, Option DPO):** 0.01 Hz to 150 Hz

Absolute Maximum Pulse Output Frequencies:

- **Standard Models (Bidirectional Outputs):** 900 Hz
- **Option P3, Option PV, Option DPO:** 200 Hz

Output Waveform: square-wave, ~50% duty cycle

- **Option PW:** programmable pulse **ON** (closed or conducting period, 1 to 65535 milliseconds

Optoisolator Outputs:

- **Isolation:** 5000 Vac RMS
- **Breakdown Voltage (collector–emitter):** 60 V (exceeding this may destroy the outputs)
- **Maximum Reverse Voltage (emitter-collector):** 5 Vdc (exceeding may destroy the outputs)
- **Maximum Leakage (OFF) Current (collector–emitter):** 100 nA
- **Recommended Load Current (collector–emitter):** 1 µA (microamp) to 5 mA (milliamp)
- **Maximum Load (collector–emitter) Current:** ~8 mA
- **Approximate ON Resistance (as measured by a DMM):** 100 Ω to 2000 Ω
- **Approximate OFF Resistance (as measured by a DMM):** > 50 MΩ

Saturation Voltage vs. Load Current: this is the typical voltage (at room temperature) measured between the **COM** terminal and **P1**, **P2**, or **P3** when the optoisolator is on (conducting). Ideally, this voltage would be zero, but instead, it varies with the load current.

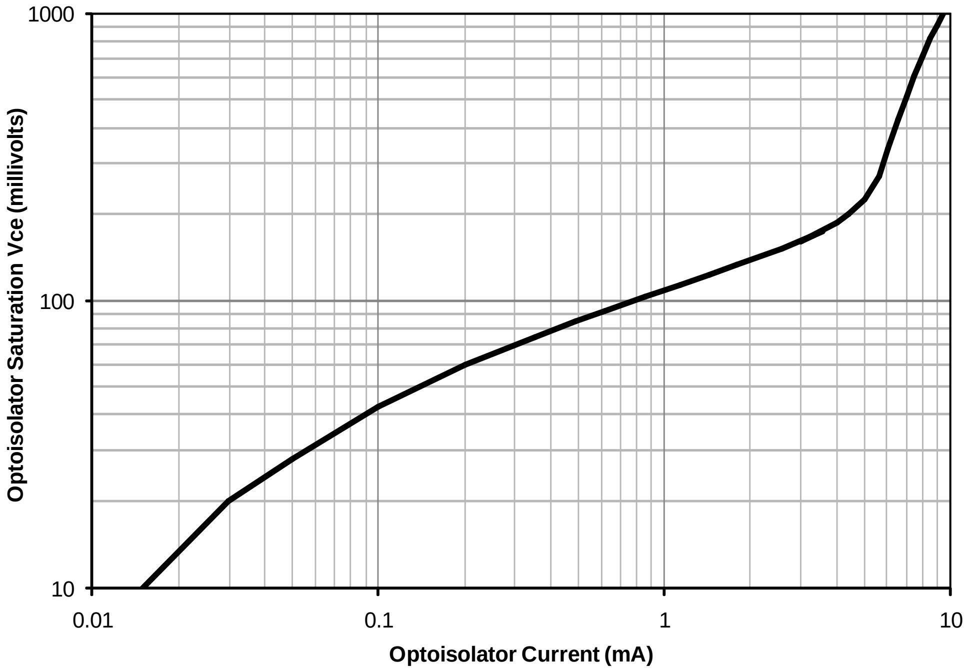


Figure 13: Optoisolator Saturation Voltage vs. Load Current

Output Rise Time (microseconds): approximately ***Rpullup / 100***, where ***Rpullup*** is the pull-up resistor value (in ohms) and the pull-up voltage is 5 Vdc. Rise time is defined as the time for the output voltage to rise from 20% to 80% of the pull-up voltage.

Output Fall Time: approximately 2-3 microseconds with a 5 Vdc pull-up voltage.

Option SSR Outputs:

Isolation: 5000 Vac RMS

Breakdown Voltage: ±60 Vdc or 40 Vac; can switch positive, negative or AC voltages

Maximum Leakage (Off) Current: 1000 nA (1 μA)

On Resistance: 1.0 to 2.5 Ω

Maximum Load Current: 500 mA

Output Turn On Time (milliseconds): 1.8 ms typical, 5.0 ms maximum

Output Turn Off Time (milliseconds): 0.5 ms typical, 2.0 ms maximum

Maximum Recommended Pulse Frequency: 30 Hz

Electrical

Power Consumption: The following table shows typical power consumption and power factor values with all three phases powered at nominal line voltages. The power supply draws most of the total power consumed, while the measurement circuitry draws 1-10% of the total (6-96 milliwatts per phase, depending on the model). Due to the design of the power supply, WattNode meters draw slightly more power at 50 Hz.

Model	Active Power at 60 Hz	Active Power at 50 Hz	Power Factor	Rated Power*	Power Supply Range	Power Supply Terminals
WNB-3Y-208-P	1.6 W	1.8 W	0.75	3 W	96 – 138 Vac	**N** and **ΦA**
WNB-3Y-400-P	1.6 W	1.8 W	0.64	3 W	184 – 264 Vac	**N** and **ΦA**
WNB-3Y-480-P	2.1 W	2.4 W	0.63	4 W	222 – 318 Vac	**N** and **ΦA**
WNB-3Y-600-P	1.2 W	1.2 W	0.47	3 W	278 – 399 Vac	**N** and **ΦA**
WNB-3D-240-P	1.7 W	1.9 W	0.63	4 W	166 – 276 Vac	**ΦA** and **ΦB**
WNB-3D-400-P	1.4 W	1.5 W	0.47	3 W	320 – 460 Vac	**ΦA** and **ΦB**
WNB-3D-480-P	1.8 W	2.2 W	0.53	4 W	384 – 552 Vac	**ΦA** and **ΦB**

Table 11: Power Supply Characteristics

**Note: This is the maximum rated power at 115% of nominal Vac at 50 Hz. This is the same as the rated power that appears on the front label of the meter.*

Maximum Operating Power Supply Voltage Range: -20% to +15% of nominal (see table above). For the WNB-3D-240-P, this is -20% of 208 Vac (166 Vac) to +15% of 240 Vac (276 Vac).

Operating Frequencies: 50/60 Hz

Measurement Category: CAT III

Measurement category III is for measurements performed in the building installation. Examples are measurements on distribution boards, circuit-breakers, wiring, including cables, bus-bars, junction boxes, switches, socket-outlets in the fixed installation, and equipment for industrial use and some other equipment, for example, stationary motors with permanent connection to the fixed installation.

The line voltage measurement terminals on the meter are rated for the following CAT III voltages (these ratings also appear on the front label):

Model	CAT III Voltage Rating
WNB-3Y-208-P WNB-3D-240-P	240 Vac
WNB-3Y-400-P WNB-3D-400-P	400 Vac
WNB-3Y-480-P WNB-3D-480-P	480 Vac
WNB-3Y-600-P	600 Vac

Table 12: WattNode CAT III Ratings

Current Transformer Inputs:

Nominal Input Voltage (At CT Rated Current): 0.33333 Vac RMS

Absolute Maximum Input Voltage: 5.0 Vac RMS

Input Impedance at 50/60 Hz: 23 kΩ

Certifications

Safety: UL 61010-1; CAN/CSA-C22.2 No. 61010-1-04; IEC 61010-1

Immunity: EN 61326: 2002 (Industrial Locations)

Electrostatic Discharge: EN 61000-4-2: 4 kV contact, 8 kV air: (B) Self-Recovering

Radiated RF Immunity: EN 61000-4-3: 10 V/m: (A) No Degradation

Electrical Fast Transient / Burst: EN 61000-4-4: 2 kV: (B) Self-Recovering

Surge Immunity: EN 61000-4-5: 1 kV I/O, 4 kV AC: (B) Self-Recovering

Conducted RF Immunity: EN 61000-4-6: 3 V: (A) No Degradation

Voltage Dips, Interrupts: EN 61000-4-11: (B) Self-Recovering

Emissions: FCC Part 15, Class B; EN 55022: 1994, Class B

Environmental

Operating Temperature: -30°C to +55°C (-22°F to 131°F)

Altitude: Up to 2000 m (6560 ft)

Operating Humidity: non-condensing, 5 to 90% relative humidity (RH) up to 40°C, decreasing linearly to 50% RH at 55°C.

Pollution: POLLUTION DEGREE 2 - Normally only non-conductive pollution; occasionally, a temporary conductivity caused by condensation must be expected.

Indoor Use: Suitable for indoor use.

Outdoor Use: Suitable for outdoor use when mounted inside an electrical enclosure (Hammond Mfg., Type EJ Series) that is rated NEMA 3R or 4 (IP 66).

Mechanical

Enclosure: High impact, ABS and/or ABS/PC plastic

Flame Resistance Rating: UL 94V-0, IEC FV-0

Size: 153 mm × 85 mm × 38 mm (6.02 in × 3.35 in × 1.50 in)

Weight: 285 gm (10.1 oz) 314 gm (11.1 oz)

Connectors: Euroblock style pluggable terminal blocks

Green: up to 12 AWG (2.5 mm^2), 600 V

Black: up to 12 AWG (2.5 mm^2), 300 V

Current Transformers

WattNode meters use CTs with built-in burden resistors generating 0.33333 Vac at rated AC current. The maximum input current rating is dependent on the CT frame size (see the tables below). Exceeding the maximum input current rating may damage CTs, but should not harm the meter.

None of these CTs measure DC current and the accuracy can be degraded in the presence of DC currents, as from half-wave rectified loads. The solid-core CTs are most susceptible to saturation due to DC currents.

WattNode meters should only be used with UL recognized current transformers, which are available from Continental Control Systems. Using non-approved transformers will invalidate the meter UL listing. The following sections list approved UL recognized current transformers.

Common CT Specifications

Type: voltage output, integral burden resistor

Output Voltage at Rated Current: 0.33333 Vac (one-third volt)

Standard CT Wire Length: 2.4 m (8 feet)

Optional CT Wire Length: up to 30 m (100 feet)

Split-Core CTs

Also called “opening” current transformers. These are UL recognized under UL file numbers E96927 or E325972: CTM-0360-**xxx**, CTS-0750-**xxx**, CTS-1250-**xxx**, CTS-2000-**xxx**, where **xxx** indicates the full scale current rating between 0005 and 1500 amps.

The accuracy of the split-core CTs are specified from 10% to 100% of rated AC current. The phase angle is specified at 50% of rated current (amps). Some low current split-core CTs have unspecified phase angle errors.

Model	Inside Diameter	Rated Amps (-xxx)	Accuracy / Phase Angle	Maximum Amps
CTM-0360-xxx	0.30" (7.5 mm)	5, 15, 30, 50, 70	±1% / <2°	100
CTS-0750-xxx	0.75” (19.0 mm)	5, 15, 30, 50	±1% / not spec.	200
CTS-0750-xxx	0.75” (19.0 mm)	70, 100, 150, 200	±1% / <2°	200
CTS-1250-xxx	1.25” (31.7 mm)	70, 100	±1% / not spec.	600
CTS-1250-xxx	1.25” (31.7 mm)	150, 200, 250, 300, 400, 600	±1% / <2°	600
CTS-2000-xxx	2.00” (50.8 mm)	600, 800, 1000, 1200, 1500	±1% / <2°	1500

Table 13: Split-core CTs

Split-Core Bus Bar CTs

These current transformers are referred to as “bus bar” CTs because they are available in larger and custom sizes appropriate for use with bus bars or multiple large conductors. These are UL recognized under UL file number E325972: CTB-**www**X**hhh**-**xxx**, where **www** and **hhh** indicate the width and height in inches, and **xxx** indicates the full scale current rating.

The accuracy of the split-core bus bar CTs is specified from 10% to 100% of rated current. The phase angle is specified at 50% of rated current (amps).

Model	Opening	Rated Amps	Accuracy / Phase Angle	Maximum Amps
CTB-1.5x3.5-0600	1.5" x 3.5" (38.1 mm x 88.9 mm)	600	±1.5% / <1.5°	750
CTB-4.0x4.0-0800	4.0" x 4.0" (101.6 mm x 101.6 mm)	800	±1.5% / <1.5°	1000
CTB-4.0x4.0-1200	4.0" x 4.0" (101.6 mm x 101.6mm)	1200	±1.5% / <1.5°	1500
CTB-4.0x4.0-2000	4.0" x 4.0" (101.6 mm x 101.6 mm)	2000	±1.5% / <1.5°	2500
CTB-4.5x4.0-3000	4.5" x 4.0" (114.3 mm x 101.6 mm)	3000	±1.5% / <1.5°	3750
CTB-wwwxhhh-xxxx	Custom (www by hhh inches)	xxxx	±1.5% / <1.5°	4000

Table 14: Split-core Bus Bar CTs

Solid-Core CTs

Also called “toroid” or “donut” current transformers. These are UL recognized under UL file number E96927: CTT-0750-100N, CTT-1250-400N, CTT-0300-030N, CTT-0500-060N, CTT-1000-200N, CTT-0300-005N, CTT-0300-015N, CTT-0500-050N, CTT-0500-030N, CTT-0500-015N, CTT-0750-070N, CTT-0750-050N, CTT-0750-030N, CTT-1000-150N, CTT-1000-100N, CTT-1000-070N, CTT-1000-050N, CTT-1250-300N, CTT-1250-250N, CTT-1250-200N, CTT-1250-150N, CTT-1250-100N, CTT-1250-070N.

The accuracy of the solid-core CTs is specified from 10% to 100% of rated current. The phase angle error is specified at 50% of rated current. The CT suffix **xxx** is the rated current. The “N” at the end of the part number indicates a nickel core material, which is the only core material available for our solid-core CTs.

Model	Inside Diameter	Rated Amps (-xxx)	Accuracy / Phase Angle	Maximum Amps
CTT-0300-xxxN	0.30" (7.6mm)	5, 15, 20, 30	±1% / <1°	30
CTT-0500-xxxN	0.50" (12.7mm)	15, 20, 30, 50, 60	±1% / <1°	60
CTT-0750-xxxN	0.75" (19.0mm)	30, 50, 70, 100	±1% / <1°	100
CTT-1000-xxxN	1.00" (25.4mm)	50, 70, 100, 150, 200	±1% / <1°	200
CTT-1250-xxxN	1.25" (31.7mm)	70, 100, 150, 200, 250, 300, 400	±1% / <1°	400

Table 15: Solid-core CTs

Warranty

All products sold by Continental Control Systems, LLC (CCS) are guaranteed against defects in material and workmanship for a period of five years from the original date of shipment. CCS’s responsibility is limited to repair, replacement, or refund, any of which may be selected by CCS at its sole discretion. CCS reserves the right to substitute functionally equivalent new or serviceable used parts.

This warranty covers only defects arising under normal use and does not include malfunctions or failures resulting from: misuse, neglect, improper application, improper installation, water damage, acts of nature, lightning, product modifications, alterations or repairs by anyone other than CCS.

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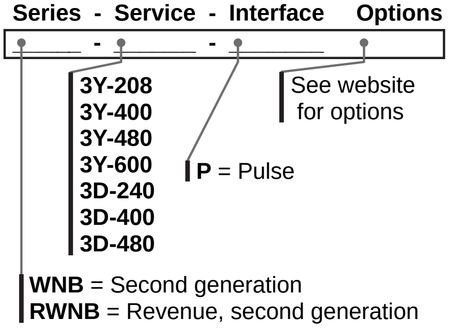
Customer acknowledges that CCS’s aggregate liability to Customer relating to or arising out of the sale or use of CCS’s products, whether such liability is asserted on the basis of contract, tort or otherwise, shall not exceed the purchase price paid by Customer for the products in respect of which damages are claimed. Customer specifically acknowledges that CCS’s price for the products is based upon the limitations of CCS’s liability set forth herein.

WattNode® Pulse
and
WattNode® Revenue
Electric Power Meter Installation Manual



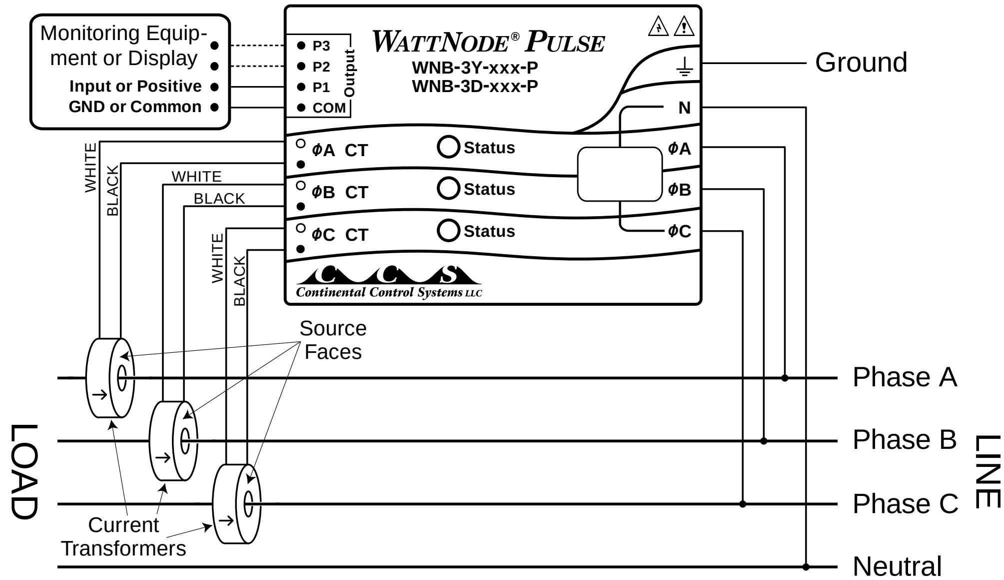


Figure 1: WattNode Wiring Diagram

1 Precautions

1.1 Only qualified personnel or **licensed electricians** should install the WattNode meter. The mains voltages of 120 to 600 Vac can be lethal!

1.2 Follow all applicable local and national electrical and safety codes.

1.3 The terminal block screws are **not** insulated. Do not contact metal tools to the screw terminals if the circuit is live!

1.4 Verify that circuit voltages and currents are within the proper range for the meter model.

1.5 Use only UL listed or UL recognized current transformers (CTs) with built-in burden resistors, that generate 0.333 Vac (333 millivolts AC) at rated current. **Do not use current output (ratio) CTs such as 1 amp or 5 amp output CTs: they will destroy the meter and may create a shock hazard.**

1.6 Protect the line voltage inputs to the meter with fuses or circuit breakers (not needed for the neutral or ground wires). See **3.3.1** below.

1.7 Equipment must be disconnected from the HAZARDOUS LIVE voltages before access.

1.8 If the meter is not installed correctly, the safety protections may be impaired.

Electrical Service (or Load) Types	Line-to-Neutral (Vac)	Line-to-Line (Vac)	WattNode Service Type	Meter Powered by
1 Phase 2 Wire 120V with neutral	96 – 138	n.a.	3Y-208	**N** and **ØA**
1 Phase 2 Wire 230V with neutral (non-U.S.)	184 – 264	n.a.	3Y-400	**N** and **ØA**
1 Phase 2 Wire 277V with neutral	222 – 318	n.a.	3Y-480	**N** and **ØA**
1 Phase 2 Wire 208V no neutral	n.a.	166 – 276	3D-240	**ØA** and **ØB**
1 Phase 2 Wire 240V no neutral	n.a.	166 – 276	3D-240	**ØA** and **ØB**
1 Phase 3 Wire 120V/240V with neutral	96 – 138	166 – 276	3Y-208	**N** and **ØA**
			3D-240	**ØA** and **ØB**
3 Phase 3 Wire Delta 208V no neutral	n.a.	166 – 276	3D-240	**ØA** and **ØB**
3 Phase 3 Wire Delta 400V no neutral (non-U.S.)	n.a.	320 – 460	3D-400	**ØA** and **ØB**
3 Phase 3 Wire Delta 480V no neutral	n.a.	384 – 552	3D-480	**ØA** and **ØB**
3 Phase 4 Wire Wye 120V/208V with neutral	96 – 138	166 – 276	3Y-208	**N** and **ØA**
			3D-240	**ØA** and **ØB**
3 Phase 4 Wire Delta 120/208/240V with neutral	96 – 138	166 – 276	3D-240	**ØA** and **ØB**
3 Phase 4 Wire Wye 230V/400V with neutral (non-U.S.)	184 – 264	320 – 460	3Y-400	**N** and **ØA**
			3D-400	**ØA** and **ØB**
3 Phase 4 Wire Wye 277V/480V with neutral	222 – 318	384 – 552	3Y-480	**N** and **ØA**
			3D-480	**ØA** and **ØB**
3 Phase 4 Wire Delta 240/415/480V with neutral	222 – 318	384 – 552	3D-480	**ØA** and **ØB**
3 Phase 4 Wire Wye 347V/600V with neutral	278 – 399	480 – 690	3Y-600	**N** and **ØA**

Table 1: WattNode Models

1.9 Symbols

⚠	Read, understand, and follow all instructions including warnings and precautions before installing and using the product.
⚡	Potential Shock Hazard from Dangerous High Voltage.
⏚	Functional ground; should be connected to earth ground if possible, but is not required for safety grounding.
cUL	UL Listing mark. This shows the UL and cUL (Canadian) listing mark.
FC	FCC Mark. This logo indicates compliance with part 15 of the FCC rules.
CE	Complies with the regulations of the European Union for Product Safety and Electro-Magnetic Compatibility. • Low Voltage Directive – EN 61010-1: 2001 • EMC Directive – EN 61327: 1997 + A1/1998 + A2/2001
V~	This indicates an AC voltage.

2 Overview

Congratulations on your purchase of the WattNode® Pulse watt/watt-hour transducer. The WattNode meter enables you to make power and energy measurements within electric service panels avoiding the costly installation of subpanels and associated wiring. It is designed for use in demand side management (DSM), submetering, and energy monitoring applications.

2.1 Additional Literature

See the Continental Control Systems, LLC website (**www.ccontrolsys.com**) for product pages, datasheets, and support pages for all WattNode meter models and current transformers. Each WattNode model has an **Operating and Reference Guide** with detailed information on the available measurements and interface.

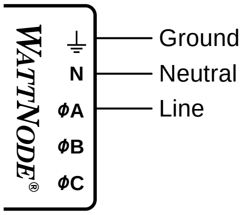
2.2 Electrical Service Types

Table 1 above lists the WattNode models and common circuit types. In the "Electrical Service Types" column, when two voltages are listed with a slash between them, they indicate the line-to-neutral / line-to-line voltages. The "Line-to-Neutral" and "Line-to-Line" columns show the operating ranges for the WattNode meters.

Connect the line voltages to the meter inputs as shown in the following figures for each service type. See **Figure 1** above for an overview.

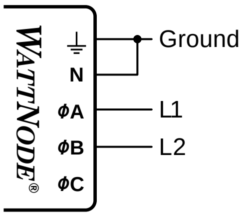
2.2.1 Single-Phase Two-Wire with Neutral

This is a common residential and branch circuit connection. Up to three such circuits may be monitored with one meter by also using the **ϕB** and **ϕC** inputs.



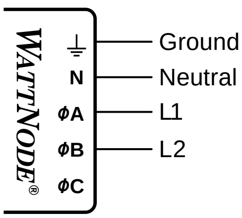
2.2.2 Single-Phase Two-Wire No Neutral

This circuit occurs in residential (commonly 120/240 Vac) and some commercial applications. The meter is powered from the **ϕA** and **ϕB** terminals. We recommend connecting the **N** terminal to ground to provide a clean voltage reference for the measurement circuitry (no current will flow through this terminal).



2.2.3 Single-Phase Three-Wire with Neutral

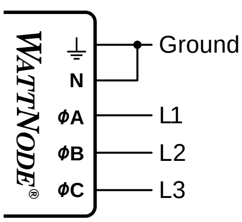
This is a common residential service at 120/240 Vac.



2.2.4 Three-Phase Three-Wire Delta No Neutral

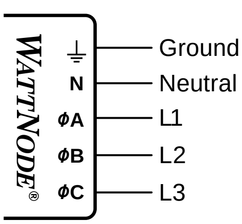
This is common in commercial and industrial settings. In some cases, the service may be four-wire, wye but the load may only be three wire (no neutral).

Occasionally, a load will only be connected to two of the three lines (say **L1** and **L2**). For this case, connect the two active lines to the **ϕA** and **ϕB** terminals and connect two CTs for the two lines.



2.2.5 Three-Phase Four-Wire Wye with Neutral

This is a common commercial and industrial service.

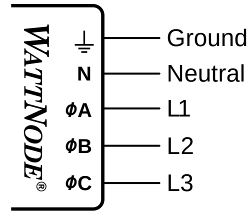


2.2.6 Three-Phase Four-Wire Delta with Neutral (Wild Leg)

The uncommon four-wire delta electrical service is a three-phase delta service with a center-tap on one of the transformer windings to create a neutral for single-phase loads.

The high-leg or phase with the higher voltage as measured to neutral has traditionally been designated "Phase B". A change to the 2008 NEC now allows the high leg of a four-wire three-phase delta service to be labeled as the "C" phase instead of the "B" phase. The WattNode meter will work correctly with the high-leg connected to **ϕA**, **ϕB**, or **ϕC**.

See the web article **Four Wire Delta Circuits** for more information.



2.2.7 Grounded Leg Service

In rare cases with delta services or single-phase two-wire services without neutral, one of the phases may be grounded.

The WattNode meter will correctly measure services with a grounded leg, but the measured voltage and power for the grounded phase will be zero and the status LEDs (if present) will not light for the grounded phase, because the voltage is near zero. Also, this type of service may result in unusual power factors.

See the web article **Grounded Leg Services** for more information.

3 Installation

3.1 Installation Checklist

See the sections referenced below for installation details.

- ☐ Mount the WattNode meter (see **3.2**).
- ☐ **Turn off power** before making line voltage connections.
- ☐ Connect circuit breakers or fuses and disconnects (see **3.3.1**).
- ☐ Connect the line voltage wires to the meter's green terminal block (see **3.3.2**).
- ☐ Mount the CTs around the line conductors. Make sure the CTs face the **source** (see **3.4**).
- ☐ Connect the twisted white and black wires from the CTs to the black terminal block on the meter, matching the wire colors to the white and black dots on the meter label (see **3.4.1**).
- ☐ Check that the CT phases match the line voltage phases (see **3.4**).
- ☐ Record the CT rated current for each meter, because it will be required during commissioning.
- ☐ Connect the output terminals of the WattNode meter to the monitoring equipment (see **3.5**).
- ☐ Check that all the wires are securely installed in the terminal blocks by tugging on each wire.
- ☐ Apply power to the meter.
- ☐ Verify that the LEDs indicate correct operation (see **4.2**).

3.2 Mounting

- Protect the meter from temperatures below –30°C (-22°F) or above 55°C (131°F), excessive moisture, dust, salt spray, or other contamination, using a NEMA rated enclosure if necessary. The meter requires an environment no worse than pollution degree 2 (normally only non-conductive pollution; occasionally, a temporary conductivity caused by condensation).
- The meter must be installed in an electrical service panel, an enclosure, or a limited access electrical room.
- **Do not** use the meter as a drilling guide; the drill chuck can damage the screw terminals and metal shavings may fall into the connectors.

The meter has two mounting holes spaced 136.6 mm (5.375 in) apart (center-to-center). These mounting holes are normally obscured by the detachable screw terminals. Remove the screw terminals to mark the hole positions and mount the meter.

Self-tapping #8 sheet metal screws are included. Don't over-tighten the screws, as long-term stress on the case can cause cracking.

3.3 Connect Voltage Terminals

3.3.1 Circuit Protection

The WattNode meter is considered "permanently connected equipment" and requires a disconnect means (circuit breaker, switch, or disconnect) and over-current protection (fuse or circuit breaker).

The meter only draws 10-30 milliamps, so the rating of any switches, disconnects, fuses, and/or circuit breakers is determined by the wire gauge, the mains voltage, and the current interrupting rating required.

- The switch, disconnect, or circuit breaker must be as close as practicable to the meter and must be easy to operate.
- Use circuit breakers or fuses rated for 20 amps or less.
- Use ganged circuit breakers when monitoring more than one line voltage.
- The circuit breakers or fuses must protect the mains terminals labeled **ϕA**, **ϕB**, and **ϕC**. If neutral is also protected, then the overcurrent protection device must interrupt both neutral and the ungrounded conductors simultaneously.
- The circuit protection / disconnect system must meet IEC 60947-1 and IEC 60947-3, as well as all national and local electrical codes.

3.3.2 Line Wiring

- **Always disconnect power** before connecting the line voltage inputs to the meter.
- For the line voltage wires, CCS recommends 16 to 12 AWG stranded wire, type THHN, MTW, or THWN, 600 V.
- Do not place more than one voltage wire in a screw terminal; use separate wire nuts or terminal blocks if needed.
- Verify that the line voltages match the line-to-line **ϕ-ϕ** and line-to-neutral **ϕ-N** values printed in the white box on the front label.

Connect each line voltage to the appropriate phase; also connect ground and neutral (if applicable). The neutral connection "**N**" is not required on delta models (3D-240, 3D-400, and 3D-480), but we recommend connecting it to ground if neutral is not present.

The screw terminals handle wire up to 12 AWG. Connect each voltage line to the green terminal block as shown in **Figure 1** above. After the voltage lines have been connected, make sure both terminal blocks are fully seated in the meter.

When power is first applied, check that the LEDs behave normally: on models with status LEDs, if you see them flashing red-green-red-green (see **Figure 7**), the line voltage is too high for this model, so disconnect the power immediately!

3.3.3 Grounding

The WattNode uses a plastic enclosure, insulation, and internal isolation barriers instead of protective earthing. The ground terminal on the green screw terminal block is a functional ground, designed to improve the measurement accuracy and noise immunity. If necessary, this terminal may be left disconnected on wye models (**-3Y**).

3.4 Connect Current Transformers

To meet the UL listing requirements, the WattNode meter may only be used with the following UL listed or UL recognized voltage output current transformer models. These all generate 333.33 millivolts AC at rated current. See the current transformer datasheets for CT ratings.

ACT-0750-**xxx**	CTL-1250-**xxx**	CTM-0360-**xxx**
CTS-0750-**xxx**	CTS-1250-**xxx**	CTS-2000-**xxxx**
CTB-**www**X**hhh**-**xxxx**	CTBL-**www**X**hhh**-**xxxx**	CTT-0300-**xxx**
CTT-0500-**xxx**	CTT-0750-**xxx**	CTT-1000-**xxx**
CTT-1250-**xxx**		

- "**xxx**" indicates the full scale current rating.
- "**www**" and "**hhh**" indicate the width and height in inches.
- "**dddd**" indicates the opening diameter of the loop for flexible Rogowski CTs.

See the web article **Selecting Current Transformers** for information on selecting appropriate current transformers (CTs).

- **Do not** use ratio or current output CTs such as 1 amp or 5 amp output models!
- See the CT datasheets for the maximum input current ratings.
- Be careful to match the CTs with the voltage phases. Make sure the **ϕA CT** is measuring the current on the same phase being monitored by **ϕA**, and the same for phases B and C. Use the supplied colored labels or colored tape to identify the CT leads.
- To minimize current measurement noise, avoid extending the CT wires, especially in noisy environments. If it is necessary to extend the wires, use twisted pair wire 22 to 14 AWG, rated for 300 V or 600 V (not less than the service voltage) and shielded if possible.
- Find the source arrow or label "THIS SIDE TOWARD SOURCE" on the CT and face/point toward the source of current.
- OPTIONAL: if you see spurious readings on unused phases, jumper the unused CT inputs: for each unused CT, connect a short wire from the terminal marked with a white dot to the terminal marked with a black dot.

To install the CTs, pass the conductor to be measured through the CT and connect the CT leads to the meter. **Always remove power before disconnecting any live conductors.** Put the line conductors through the CTs as shown in **Figure 1** above.

CTs are directional. If they are mounted backwards or with their white and black wires swapped the measured power will be negative. The status LEDs indicate negative measured power by flashing red.

Split-core CTs can be opened for installation around a conductor. A nylon cable tie may be secured around the CT to prevent inadvertent opening.

3.4.1 CT Wiring

Connect the white and black CT wires to the meter terminals marked **ϕA CT**, **ϕB CT** , and **ϕC CT** (see **Figure 1** above). Excess length may be trimmed from the wires if desired. The current transformers connect to the six position black screw terminal block. Connect each CT with the white wire aligned with the white dot on the label, and the black wire aligned with the black dot. Note the order in which the phases are connected, as the line voltage phases **must** match the current phases for accurate power measurement.

3.5 Connect the Output Signals

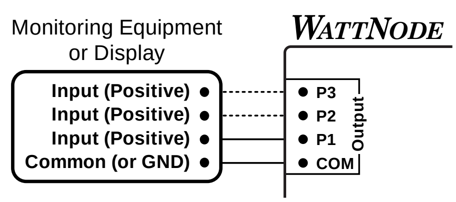
- The meter outputs are isolated from dangerous voltages, so you can connect them at any time.
- If the output wiring is near line voltage wiring, use wires or cables with a 300 V or 600 V rating (not less than the service voltage).
- If the output wiring is near bare conductors, it should be double insulated or jacketed.
- You may install two wires into each screw terminal by twisting the wires together, inserting them into terminal, and securely tightening. Note: a loose wire can disable an entire network section.
- Use twisted-pair cable (unshielded or shielded) to prevent interference.

3.5.1 WattNode Pulse Outputs

Use the following directions when connecting the pulse outputs of a WattNode Pulse meter.

- The outputs **P1**, **P2**, and **P3** should not be connected to negative voltages, or to voltages greater than +60 Vdc.
- For long distances, use shielded twisted-pair cable to prevent interference. With shielded cable, connect the shield to earth ground at one end.
- If you need to add pull-up resistors, see the **Operating and Reference Guide**.

The WattNode pulse outputs may be connected to most devices that expect a contact closure or relay input. See the **Operating and Reference Guide** for more complex connection information.



The following table shows the pulse output channel assignments for the standard bidirectional outputs and for the optional per-phase outputs ***(Option P3)***.

Pulse Outputs	P1 Output	P2 Output	P3 Output
Standard Outputs - Bidirectional	Positive energy - all phases	Negative energy - all phases	Not used
Option P3 Per-Phase Outputs	Phase A positive energy	Phase B positive energy	Phase C positive energy
Option PV Photovoltaic	Phase A+B pos. energy	Phase A+B neg. energy	Phase C positive energy
Option DPO Dual Positive Outputs	Positive energy - all phases	Negative energy - all phases	Positive energy - all phases

Table 2: Pulse Output Assignments

4 Operation

4.1 Initial Configuration

For WattNode Pulse meters, the only required configuration will be in the data logger or pulse counting device, which must be configured with the correct scale factors to convert from pulses to energy (kWh).

For details on configuring the WattNode meter, see the appropriate **Operating and Reference Guide** for your model.

The meter does not include a display or buttons, so it is not possible to configure or monitor the meter directly, other than the basic LED diagnostics described below.

4.2 Power Status LEDs

The three status LEDs on the front of the meter can help indicate correct operation. The "**A**", "**B**", and "**C**" on the diagrams indicate the three phases.

4.2.1 Normal Startup

The meter displays the following startup sequence whenever power is first applied.

A	Red	Yellow	Green
B	Red	Yellow	Green
C	Red	Yellow	Green
	1.0sec	1.0sec	1.0sec

4.2.2 Positive Power

Any phase with the LEDs flashing green is indicating normal positive power.

Green	Off	Green	Off	Green	Off

4.2.3 No Power

Any phase with a solid green LED indicates no power, but line voltage is present.

Green

4.2.4 No Voltage

Any phase LED that is off indicates no voltage on that phase.

Off

4.2.5 Negative Power

Red flashing indicates negative power for that phase. Reversed CTs, swapped CT wires, or CTs not matched with line voltage phases can cause this.

Red	Off	Red	Off	Red	Off

4.2.6 Overvoltage Warning

The following indicates that the line voltage is too high for this model. **Disconnect power immediately!** Check the line voltages and the meter ratings (in the white box on the label).

A	R	G	R	G	R	G	R	G	R	G	R	G
B	R	G	R	G	R	G	R	G	R	G	R	G
C	R	G	R	G	R	G	R	G	R	G	R	G
	1.0sec											

4.2.7 Meter Not Operating

If none of the LEDs light, then check that the correct line voltages are applied to the meter. If the voltages are correct, call customer service for assistance.

A	Off
B	Off
C	Off

4.2.8 WattNode Error

If the meter experiences an internal error, it will light all LEDs red for three or more seconds. If you see this happen repeatedly, return the meter for service.

A	Red
B	Red
C	Red
	3.0sec

For other LED patterns, see the **Operating and Reference Guide** or contact support for assistance.

4.3 Monitoring

The meter does not include a display or buttons, so it is not possible to operate the meter directly. The following is a brief overview of the possible remote monitoring.

The WattNode Pulse models uses optoisolator outputs that simulate contact closures. These are generally connected to a datalogger or similar monitoring device which can count pulses to measure energy. See the **Operating and Reference Guide** for equations to scale pulse counts and frequencies to energy and power.

4.4 Maintenance and Repair

The WattNode meter requires no maintenance. It is not user serviceable and there are no replaceable parts except the pluggable screw terminals. There are no diagnostic tests that can be performed by the user, other than checking for errors via the status LEDs.

In the event of any failure, the meter must be returned for service (contact CCS for an RMA). For a new installation, follow the diagnostic and troubleshooting instructions in the **Operating and Reference Guide** before returning the meter for service, to ensure that the problem is not connection related.

The WattNode meter should not normally need to be cleaned, but if cleaning is desired, power must be disconnected first and a dry or damp cloth or brush should be used.

5 Specifications

The following is a list of basic specifications. For extended specifications, see the **Operating and Reference Guide**.

5.1 Accuracy

The following accuracy specifications do not include errors caused by the current transformer accuracy or phase angle errors. "Rated current" is the current that generates a CT output voltage of 0.33333 Vac.

5.1.1 Normal Operation

- **Line voltage**: -20% to +15% of nominal
- **Power factor**: 1.0
- **Frequency**: 48 - 62 Hz
- **Ambient Temperature**: 23°C ± 5°C
- **CT Current**: 5% - 100% of rated current

Accuracy: ±0.5% of reading

For accuracy at other conditions, see the reference guide.

5.2 Measurement

Update Rate: Internally, all measurements are performed at this rate.

- ~200 milliseconds

Start-Up Time: the meter starts measuring power/energy and reporting measurements or generating pulses this long after AC voltage is applied

- ~500 milliseconds

Default CT Phase Angle Correction: 0.0 degrees.

5.3 Models and Electrical Specifications

The service "3Y-208" applies to the model WNB-3Y-208-P, RWNB-3Y-208-P, and so on for the other service types.

Service	Nominal Vac Line-to-Neutral	Nominal Vac Line-to-Line	Phases	Wires
3Y-208	120	208–240	1 - 3	2 - 4
3Y-400	230	400	1 - 3	2 - 4
3Y-480	277	480	1 - 3	2 - 4
3Y-600	347	600	1 - 3	2 - 4
3D-240	120*	208–240	1 - 3	2 - 4
3D-400	230*	400	3	2 - 4
3D-480	277*	480	3	2 - 4

Table 3: WattNode Model Service Types

*Note: the delta models have an optional neutral connection that may be used for measuring wye circuits. In the absence of neutral, voltages are measured with respect to ground. Delta WattNode models use the phase A and phase B connections for power.

Over-Voltage Limit: 125% of nominal Vac. Extended over-voltage operation can damage the WattNode and void the warranty.

Over-Current Limit: 120% of rated current. Exceeding 120% of rated current will not harm the WattNode meter but the current and power will not be measured accurately.

Maximum Surge: 4kV according to EN 61000-4-5

Power Consumption: The following tables shows maximum volt-amperes, the power supply ranges, typical power consumption, and typical power factor values with all three phases powered at nominal line voltages. The power supply draws most of the total power consumed, while the measurement circuitry draws 1-10% of the total (6-96 milliwatts per phase, depending on the model). Due to the design of the power supply, WattNode meters draw slightly more power at 50 Hz.

Service	Rated VA (1)	Power Supply Range (Vac)	Power Supply Terminals
3Y-208	4 VA	96 – 138	**N** and **ϕA**
3Y-400	4 VA	184 – 264	**N** and **ϕA**
3Y-480	4 VA	222 – 318	**N** and **ϕA**
3Y-600	4 VA	278 – 399	**N** and **ϕA**
3D-240	4 VA	166 – 276	**ϕA** and **ϕB**
3D-400	3 VA	320 – 460	**ϕA** and **ϕB**
3D-480	3 VA	384 – 552	**ϕA** and **ϕB**

Table 4: Service Volt-Amperes and Power Supply Range

(1) Note: The **Rated VA** is the maximum at 115% of nominal Vac at 50 Hz. This is the same as the value that appears on the front label of the meter.

Service	Real Power (60 Hz)	Real Power (50 Hz)	Power Factor
3Y-208	1.6 W	1.8 W	0.75
3Y-400	1.6 W	1.8 W	0.64
3Y-480	2.1 W	2.4 W	0.63
3Y-600	1.2 W	1.2 W	0.47
3D-240	1.7 W	1.9 W	0.63
3D-400	1.4 W	1.5 W	0.47
3D-480	1.8 W	2.2 W	0.53

Table 5: Power Consumption

Maximum Power Supply Voltage Range: -20% to +15% of nominal (see table above). For the 3D-240 service, this is -20% of 208 Vac (166 Vac) to +15% of 240 Vac (276 Vac).

Operating Frequencies: 50/60 Hz

Measurement Category: CAT III

Measurement category III is for measurements performed in the building installation. Examples are measurements on distribution boards, circuit-breakers, wiring, including cables, bus-bars, junction boxes, switches, socket-outlets in the fixed installation, and equipment for industrial use and some other equipment, for example, stationary motors with permanent connection to the fixed installation.

The line voltage measurement terminals on the meter are rated for the following CAT III voltages (these ratings appear on the front label):

Service	CAT III Voltage Rating
3Y-208 3D-240	240 Vac
3Y-400 3D-400	400 Vac
3Y-480 3D-480	480 Vac
3Y-600	600 Vac

Table 6: WattNode CAT III Ratings

Current Transformer Inputs:

Nominal Input Voltage (At CT Rated Current): 0.33333 Vac RMS

Absolute Maximum Input Voltage: 5.0 Vac RMS

Input Impedance at 50/60 Hz: 23 kΩ

5.4 Pulse Outputs

Full-Scale Pulse Frequencies:

Standard (All Models): 4.00 Hz

Custom (Bidirectional): 0.01 Hz to 600 Hz

Custom (Option P3, Option PV, Option DPO): 0.01 Hz to 150 Hz

Absolute Maximum Pulse Output Frequencies:

Standard Models (Bidirectional): 900 Hz

Option P3, Option PV, Option DPO: 200 Hz

Output Waveform: square-wave, ~50% duty cycle

Option PW: programmable pulse **ON** (closed or conducting period, 1 to 65535 milliseconds

Optoisolator Outputs:

Isolation: 5000 Vac RMS

Breakdown Voltage (collector–emitter): 60 V (exceeding this may destroy the outputs)

Maximum Reverse Voltage (emitter-collector): 5 Vdc (exceeding may destroy the outputs)

Maximum Leakage (OFF) Current (collector–emitter): 100 nA

Recommended Load Current (collector–emitter): 1 μA (microamp) to 5 mA (milliamp)

Maximum Load Current: ~8 mA

5.5 Certifications

Safety:

- UL 61010-1
- CAN/CSA-C22.2 No. 61010-1-04
- IEC 61010-1

Immunity: EN 61326: 2002 (Industrial Locations)

Electrostatic Discharge: EN 61000-4-2

Radiated RF Immunity: EN 61000-4-3

Electrical Fast Transient / Burst: EN 61000-4-4

Surge Immunity: EN 61000-4-5

Conducted RF Immunity: EN 61000-4-6

Voltage Dips, Interrupts: EN 61000-4-11

Emissions:

- FCC Part 15, Class B
- EN 55022: 1994, Class B

5.6 Environmental

Operating Temperature: -30°C to +55°C (-22°F to 131°F)

Altitude: Up to 2000 m (6560 ft)

Operating Humidity: non-condensing, 5 to 90% relative humidity (RH) up to 40°C, decreasing linearly to 50% RH at 55°C.

Pollution: POLLUTION DEGREE 2 - Normally only non-conductive pollution; occasionally, a temporary conductivity caused by condensation must be expected.

Indoor Use: Suitable for indoor use.

Outdoor Use: Suitable for outdoor use if mounted inside an electrical enclosure (Hammond Mfg., Type EJ Series) rated NEMA 3R or 4 (IP 66).

5.7 Mechanical

Enclosure: High impact, ABS/PC plastic

Flame Resistance Rating: UL 94V-0, IEC FV-0

Size: 153 mm × 85 mm × 38 mm (6.02 in × 3.35 in × 1.50 in)

Connectors: Euroblock pluggable terminal blocks

Green: up to 12 AWG (2.5 mm^2), 600 V

Black: up to 12 AWG (2.5 mm^2), 300 V

5.8 FCC Information

This equipment has been tested and complies with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

The FCC limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- Reorient or relocate the receiving antenna.
- Increase the separation between the equipment and receiver.
- Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.
- Consult the dealer or an experienced radio/TV technician for help.

5.9 Warranty

All products sold by Continental Control Systems, LLC (CCS) are guaranteed against defects in material and workmanship for a period of five years from the original date of shipment. CCS's responsibility is limited to repair, replacement, or refund, any of which may be selected by CCS at its sole discretion. CCS reserves the right to substitute functionally equivalent new or serviceable used parts.

WattNode Logger models include a lithium battery to preserve the date and time during power failures. CCS will replace or provide a replacement battery at no charge if the battery fails within five years from the original date of shipment.

This warranty covers only defects arising under normal use and does not include malfunctions or failures resulting from: misuse, neglect, improper application, improper installation, water damage, acts of nature, lightning, product modifications, alterations or repairs by anyone other than CCS.

Except as set forth herein, CCS makes no warranties, expressed or implied, and CCS disclaims and negates all other warranties, including without limitation, implied warranties of merchantability and fitness for a particular purpose.

5.10 Limitation of Liability

In no event shall CCS be liable for any indirect, special, incidental, punitive or consequential damages of any kind or nature arising out of the sale or use of its products whether such liability is asserted on the basis of contract, tort or otherwise, including without limitation, lost profits, even if CCS has been advised of the possibility of such damages.

Customer acknowledges that CCS's aggregate liability to Customer relating to or arising out of the sale or use of CCS's products, whether such liability is asserted on the basis of contract, tort or otherwise, shall not exceed the purchase price paid by Customer for the products in respect of which damages are claimed. Customer specifically acknowledges that CCS's price for the products is based upon the limitations of CCS's liability set forth herein.

Document Number: WN-Inst-P-1.01
Revision Date: April 18, 2013

Continental Control Systems, LLC
3131 Indian Rd., Boulder, CO 80301, U.S.A.
(303) 444-7422, **http://www.ccontrolsys.com**

HOBO® Pendant® Temperature/Light Data Logger (UA-002-xx) Manual

HOBO Pendant Temperature/Light Data Logger

Models: UA-002-08
UA-002-64

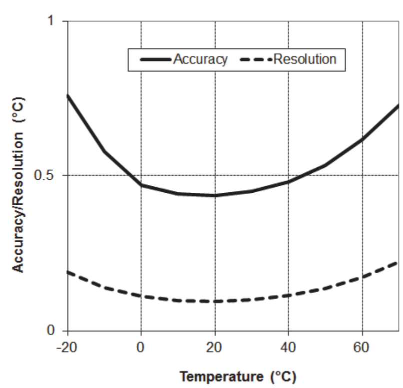
Required Items:

- HOBOware 2.x or later
- USB cable (included with software)
- Pendant Optic USB Base Station & Coupler (BASE-U-1)
- Optic USB Base Station (BASE-U-4) or HOBO Waterproof Shuttle (U-DTW-1) & Coupler (COUPLER2-A)

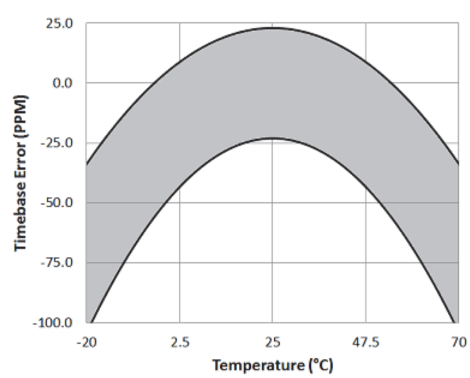
The HOBO Pendant Temperature/Light Data Logger is a waterproof, two-channel logger with 10-bit resolution and can record up to approximately 3,500 (8K model) or 28,000 (64K model) combined temperature and light readings or internal logger events. The logger uses a coupler and optical base station with USB interface for launching and data readout by a computer.

Specifications

Measurement Range	Temperature: -20° to 70°C (-4° to 158°F) Light: 0 to 320,000 lux (0 to 30,000 lumens/ft^2)
Accuracy	Temperature: ± 0.53°C from 0° to 50°C (± 0.95°F from 32° to 122°F), see Plot A Light intensity: Designed for measurement of relative light levels, see Plot D for light wavelength response
Resolution	Temperature: 0.14°C at 25°C (0.25°F at 77°F), see Plot A
Drift	Less than 0.1°C/year (0.2°F/year)
Response Time	Airflow of 2 m/s (4.4 mph): 10 minutes, typical to 90% Water: 5 minutes, typical to 90%
Time Accuracy	±1 minute per month at 25°C (77°F), see Plot B
Operating Range	In water/ice: -20° to 50°C (-4° to 122°F) In air: -20° to 70°C (-4° to 158°F)
Water Depth Rating	30 m from -20° to 20°C (100 ft from -4° to 68°F), see Plot C
NIST Traceable Certification	Available for temperature only at additional charge; temperature range -20° to 70°C (-4° to 158°F)
Battery Life	1 year typical use
Memory	UA-002-08: 8K bytes (approximately 3.5K combined temperature and light readings or events) UA-002-64: 64K bytes (approximately 28K combined temperature and light readings or events)
Materials	Polypropylene case; stainless steel screws; Buna-N o-ring
Weight	18 g (0.6 oz)
Dimensions	58 x 33 x 23 mm (2.3 x 1.3 x 0.9 inches)
CE	The CE Marking identifies this product as complying with all relevant directives in the European Union (EU).

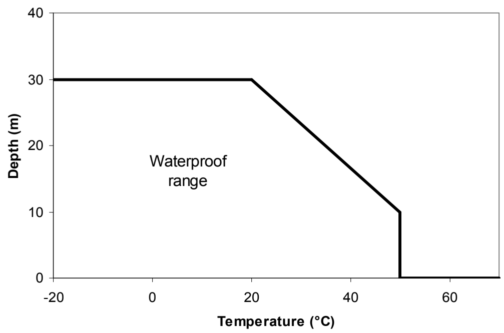


Plot A

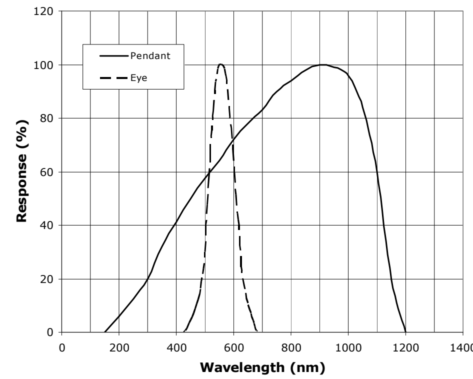


Plot B

Specifications (continued)



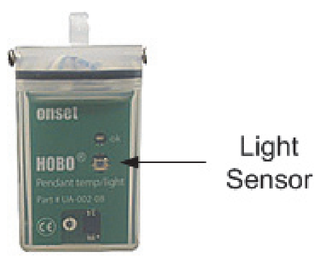
Plot C



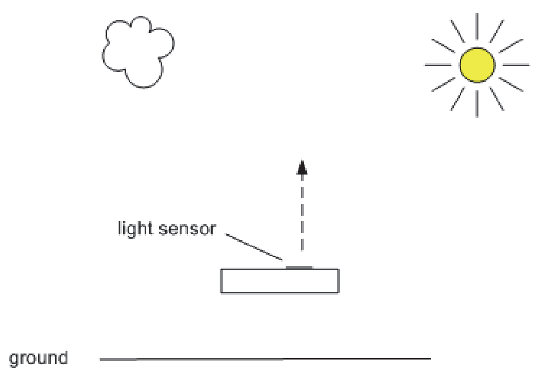
Plot D

Deployment/Mounting

The Light Sensor response is roughly cosine dependent with the angle from vertical. Therefore, whether outdoors or underwater, the logger must be mounted horizontally so that the sensor is pointing straight up towards the sky.



Attach the logger to a flat surface using glue, a tie, or a rubber band, making sure that the sensor is pointing up.



Connecting the Logger to a Computer

The HOBO Pendant logger requires either of the following to connect to the computer:

- Pendant Optic USB Base Station & Coupler (BASE-U-1); HOBOware 2.1 or later

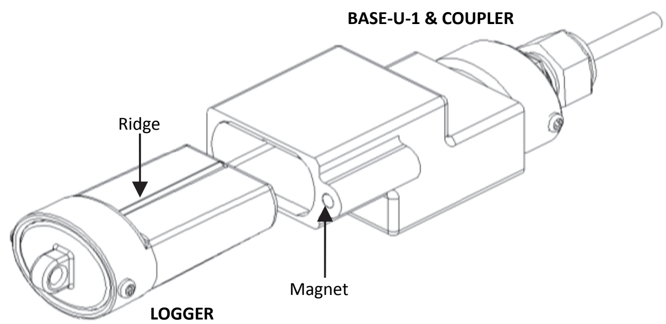
  OR

- Optic USB Base Station (BASE-U-4) or HOBO Waterproof Shuttle (U-DTW-1); coupler (COUPLER2A); HOBOware 2.2 or later

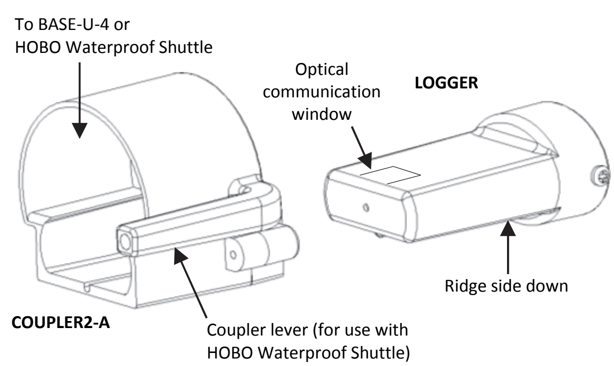
If possible, avoid connecting at temperatures below 0°C (32°F) or above 50°C (122°F).

1. Plug the USB connector on the base station into an available USB port on your computer.
2. Insert the logger and the base station into the coupler, as shown in the following diagrams.

   For BASE-U-1, make sure that the logger is inserted in the end of the coupler that has the magnet, and that the ridges on the base station and logger are aligned with the grooves in the coupler.



   For BASE-U-4 or the HOBO Waterproof Shuttle, firmly insert the optical end of the base station into the D-shaped end of the coupler, and make sure that the ridge on the logger is aligned with the groove in the coupler.



3. If you are using the HOBO Waterproof Shuttle, briefly press the coupler lever to put the shuttle into base station mode.
4. If the logger has never been connected to the computer before, it may take a few seconds for the new hardware to be detected.

5. Use the logger software to set up the alarms, launch, and read out the logger.

You can read out the logger or check its status while it continues to log, stop it manually with the software, or let it record data until the memory is full. Refer to the software user's guide for complete details on launching, reading out, and viewing data from the logger.

Important: Do not cover the optical communication window in the logger (shown in diagram above) with a label or sticker as that may interfere with the communications with the base station or shuttle.

Triggered Start

This logger can be configured to start at your command, using the magnet in the coupler to trigger a start.

1. Use HOBOware to launch the logger with Using Coupler selected. Remove the logger from the coupler.
2. Bring the logger and an empty coupler or strong magnet to the deployment location.

Important: Any magnet can trigger a start. This can be helpful, but it can also cause a premature start. Keep the logger away from strong magnetic fields until you are ready to begin logging.

3. When you are ready for the logger to start logging, insert the logger into the empty coupler (or place it next to a strong magnet) and remove it after three seconds.

Important: The logger will not launch if the base station is in the coupler.

4. Verify that the logger's light is blinking at least every four seconds.

Sample and Event Logging

The logger can record two types of data: samples and internal logger events. Samples are the measurements recorded at each logging interval (for example, temperature every minute). Events are independent occurrences triggered by a logger activity, such as Bad Battery or Host Connected. Events help you determine what was happening while the logger was logging.

Operation

A light (LED) on the front of the logger confirms logger operation. The following table explains when the light blinks during logger operation.

When:	The light:
The logger is logging	Blinks once every one to four seconds (the shorter the logging interval, the faster the light blinks); blinks when logging a sample
The logger is awaiting a start because it was configured to start logging At Interval, On Date/Time, or Using Coupler	Blinks once every eight seconds until logging begins

Light Measurement

The logger measures light intensity in units of lumens per square foot (US) or lux (SI). The light sensor in the Pendant logger measures a much broader spectrum of light wavelengths than are visible to the human eye. Plot D shows that the logger's response extends farther into ultraviolet and infrared wavelengths than the eye's response. This means the logger is useful for sensing wavelengths not visible to the eye, but it also may mean that the logger's readings will not correspond exactly to measurements made with a device having different spectral sensitivity. The light sensor is most useful for determining relative changes, rather than absolute values of intensity.

The logger has a very wide dynamic range of light sensitivity extending from complete darkness to somewhat beyond full daylight. The resolution steps are smaller at low light levels than at high light levels to allow useful measurements across this broad range of intensities. Intensity readings are maximum for light hitting the sensor directly on-axis and are reduced for light coming in at an angle. Readings can also be reduced by abrasions or dirt on the case above the light sensor.

Protecting the Logger

The logger can be damaged if the water depth rating is exceeded. The depth rating is approximately 30 m (100 ft) at temperatures below 20°C (68°F), but is less in warmer water. Refer to Plot C for details.

Do not store the logger in the coupler. Remove the logger from the coupler when you are not using it. When the logger is in the coupler or near a magnet, it consumes more power and will drain the battery prematurely.

Keep the logger away from magnets. Being near a magnet can cause false coupler events to be logged. It can also launch the logger prematurely if it was waiting for a trigger start.

Note! Static electricity may cause the logger to stop logging. To avoid electrostatic discharge, transport the logger in an anti-static bag, and ground yourself by touching an unpainted metal surface before handling the logger. For more information, search for "static discharge" in the FAQ section on onsetcomp.com.

Periodically inspect the desiccant and dry it if it is not bright blue. The desiccant pack is located in the cap of the logger. To dry the desiccant, remove the desiccant pack from the cap and leave the pack in a warm, dry location until the bright blue color is restored. (Refer to the *Battery* section for instructions on removing and replacing the logger cap.)

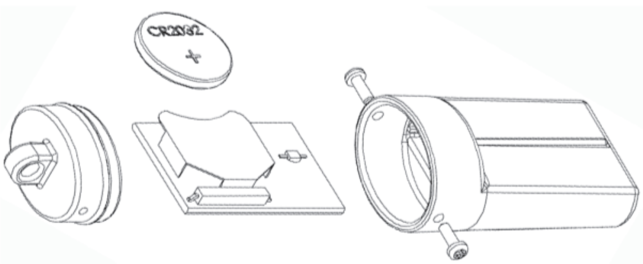
Temperature Range	Desiccant Maintenance Schedule
Less than 30°C (86°F)	Approximately once per year
30° to 40°C (86° to 104°F)	Approximately every six months
Over 40°C (104°F)	Approximately every three months

Battery

The logger requires one 3-Volt CR-2032 lithium battery. Battery life varies based on the temperature and the frequency at which the logger is recording data (the logging interval). A new battery typically lasts one year with logging intervals greater than one minute. Deployments in extremely cold or hot temperatures, or logging intervals faster than one minute, may significantly reduce battery life. Continuous logging at the fastest logging rate of one second will deplete the battery in as little as two weeks.

To replace the battery:

1. Remove the two screws that secure the end cap to the case and remove the cap.
2. Examine the desiccant pack that is tucked into the cap. If the desiccant is not bright blue, put the desiccant pack in a warm, dry place until the blue color is restored.
3. Gently tap the case to loosen the circuit board and remove it from the case.



4. Carefully push the battery out of the holder with a small, nonmetallic blunt instrument.
5. Insert a new battery, positive side facing up.
6. Return the circuit board and label to the case, carefully aligning the circuit board with the grooves in the case so that the battery faces the ridged side of the case.
7. Replace the end cap, ensuring that the desiccant pack is tucked into the cap, and the o-ring is seated in the groove, not pinched or twisted. Make sure no dirt or lint is trapped on the o-ring, as this could result in a leak.
8. Re-fasten the screws. Do not over-tighten the screws.

WARNING: Do not cut open, incinerate, heat above 85°C (185°F), or recharge the lithium battery. The battery may explode if the logger is exposed to extreme heat or conditions that could damage or destroy the battery case. Do not dispose of the logger or battery in fire. Do not expose the contents of the battery to water. Dispose of the battery according to local regulations for lithium batteries.

HOBO® Occupancy/Light Data Logger (UX90-005x/-006x) Manual

UX90-005x

UX90-006x

HOBO Occupancy/Light Data Logger

Models: UX90-005
UX90-005M
UX90-006
UX90-006M

Included Items:

- Command™ strip
- Double-sided tape
- Hook & loop strap

Required Items:

- HOBOware 3.3 or later
- USB cable (included with software)

Accessories:

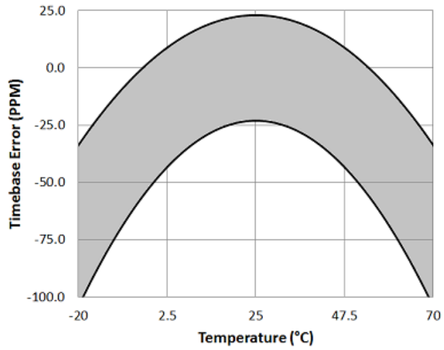
- Light pipe (UX90-LIGHT-PIPE-1)
- U-Shuttle (U-DT-1)

The HOBO Occupancy/Light data logger monitors room occupancy up to 5 or 12 meters away (depending on the model) as well as indoor light changes with its integrated sensors. Using HOBOware®, you can easily configure both channels to record occupancy and light on and off conditions for building energy audits. This compact data logger has a built-in LCD screen for checking status, remaining battery level, and memory consumption. You can also use the LCD screen to quickly calibrate the logger to the light level in the room or select preset sensitivity thresholds with HOBOware. There are two models of both types of loggers: the UX90-005/-006 has a memory capacity of 128 KB while the UX90-005M/-006M has 512 KB.

Specifications

Occupancy Sensor	
Detection Range	UX90-005x: maximum 5 m (16.4 ft) UX90-006x: maximum 12 m (39.4 ft)
Detection Performance	UX90-005x: 94° (±47°) Horizontal; 82° (±41°) Vertical (see Figure A) UX90-006x: 102° (±51°) Horizontal; 92° (±46°) Vertical (see Figure B)
Detection Zones	UX90-005x: 64 (see Figure A) UX90-006x: 92 (see Figure B)
Light Sensor	
Light Threshold	> 65 lux
Light Type	LED, CFL, fluorescent, HID, incandescent, natural
Logger	
Memory Modes	Wrap when full or stop when full
Start Modes	Immediate, push button, date & time, or next interval
Stop Modes	When memory full, push button, or date & time
Time Accuracy	±1 minute per month at 25°C (77°F) (see Plot A)
Battery Life	1 year typical use
Battery Type	One 3V CR2032 lithium battery
Memory	UX90-005/-006: 128 KB (84,650 measurements, maximum) UX90-005M/-006M: 512 KB (346,795 measurements, maximum)
Download Type	USB 2.0 interface
Full Memory Download Time	10 seconds for 128 KB, 30 seconds for 512 KB
Operating Range	Logging: -20° to 70°C (-4° to 158°F); 0 to 95% RH (non-condensing) Launch/Readout: 0° to 50°C (32° to 122°F) per USB specification Occupancy Sensor Range: 20° to 60°C (-4° to 140°F); 15 to 85% RH (non-condensing)
LCD	LCD is visible from: 0° to 50°C (32° to 122°F); the LCD may react slowly or go blank in temperatures outside this range
Size	UX90-005x: 3.66 x 8.48 x 2.36 cm (1.44 x 3.34 x 0.93 in.) UX90-006x: 3.66 x 8.48 x 2.87 cm (1.44 x 3.34 x 1.13 in.)
Weight	30 g (1.06 oz)
Environmental Rating	IP50
CE	The CE Marking identifies this product as complying with all relevant directives in the European Union (EU).

Specifications (continued)



Plot A: Time Accuracy

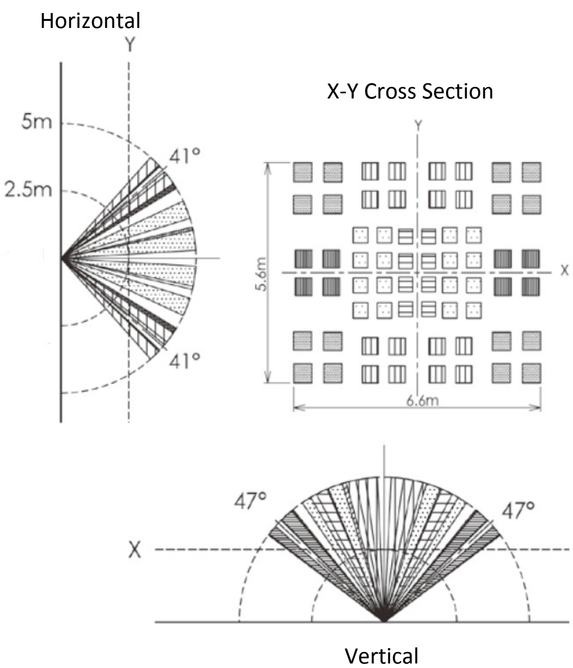


Figure A: UX90-005 Detection Area

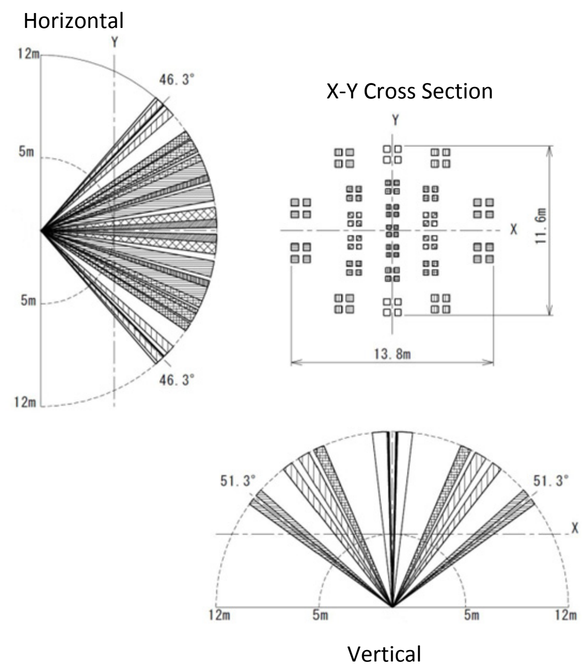
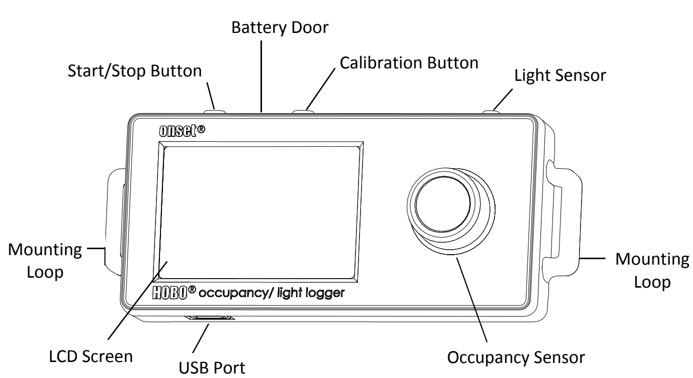


Figure B: UX90-006 Detection Area

Logger Components and Operation



Start/Stop Button: Press this button for 3 seconds to start or stop logging data. This requires configuring the logger in HOBOware with a push button start or stop (see *Setting up the Logger*). You can also press this button for 1 second to record an internal event (see *Recording Internal Logger Events*) or to turn the LCD screen on if the option to turn off the LCD has been enabled (see *Setting up the Logger*).

Battery door: Open the battery door (not visible in the diagram) on the top of the logger to access the logger battery (see *Battery Information*).

Calibration Button: Press this button to calibrate the logger for the light you will be monitoring. See *Calibrating the Light Sensor* for more details.

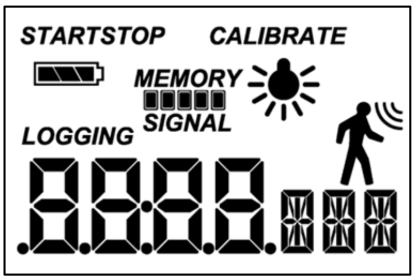
Light Sensor: This built-in sensor monitors light on and off conditions.

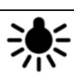
Mounting Loops: Use the two mounting loops to mount the logger with the hook-and-loop strapping (see *Mounting the Logger*).

Occupancy Sensor: This sensor determines whether the room is occupied or unoccupied. The UX90-005x model is shown here.

USB Port: Use this port to connect the logger to the computer or the HOBO U-Shuttle via USB cable (see *Setting up the Logger* and *Reading Out the Logger*).

LCD Screen: This logger is equipped with an LCD screen that displays details about the current status. This example shows all symbols illuminated on the LCD screen followed by definitions of each symbol in the following table.



LCD Symbol	Description
START	The logger is waiting to be launched. Press and hold the Start/Stop button for 3 seconds to launch the logger.
STOP	The logger has been launched with a push button stop enabled; press and hold the Start/Stop button for 3 seconds to stop the logger. **Note**: If you also launched the logger with a push button Start, this symbol will not appear on the display for 5 minutes.
	The battery indicator shows the approximate battery power remaining.
MEMORY 	If the logger has been configured to stop logging when memory fills, the memory bar indicates the approximate space remaining in the logger to record data. In this example, the logger memory is almost full.
MEMORY 	If the logger has been configured to never stop logging (wrapping enabled), then a single block will blink starting at the left and moving right over time. Each block represents a segment of memory where the data is being recorded. In this example, the middle block is blinking.
	The room is occupied.
	The room is unoccupied.
	The light is on.
	The light is off.
LOGGING	The logger is currently logging.
CALIBRATE	The logger can be calibrated. See *Calibrating the Light Sensor* for more details.
 SIGNAL	This shows the signal strength of the light being monitored. In this example, the signal strength is at full scale. See *Calibrating the Light Sensor* for more details.

LCD Symbol	Description
05:38 M-S	**Time display when logger is logging:** This shows the total amount of time the room has been occupied or the light has been on since logging began, ranging from seconds to days. This example indicates the room has been occupied or the light has been on for a total of 5 minutes and 38 seconds. The logger must be launched with the LCD set to show "Time" for this symbol to display. **Time display when logger is stopped:** This indicates the logger has been configured to start logging on a particular date/time. The display will count down to the start date/time until logging begins. In this example, 5 minutes and 38 seconds remain until logging will begin.
24%	This shows the percentage of time the room has been occupied or the light has been on since logging began. This example indicates the room has been occupied or the light has been on for a total of 24% of the time since logging began. The logger must be launched with the LCD set to show "%" for this symbol to display.
StoP	The logger has been stopped.

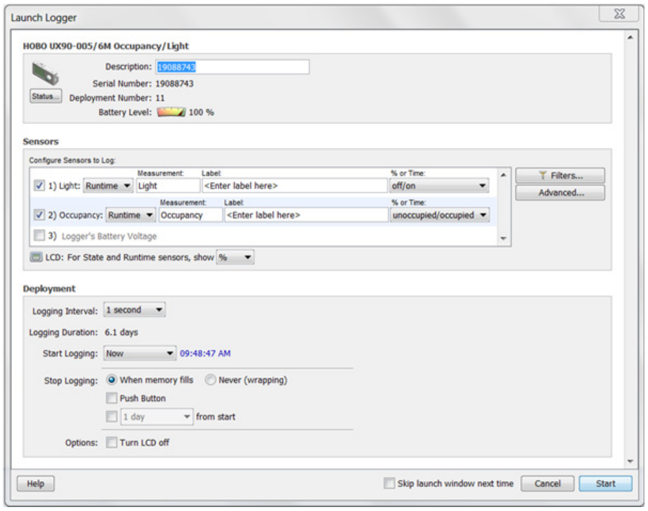
Notes:

- You can disable the LCD screen when logging. Select "Turn LCD Off" when setting up the logger as described in the next section. When this option is enabled, you can still temporarily view the LCD screen by pushing the Start/Stop button or Calibration button for 1 second. The LCD will then remain on for 10 minutes.
- When the logger has stopped logging, the LCD screen will remain on until the logger is offloaded to a computer or HOBO U-Shuttle (unless launched with the "Turn LCD Off" option). Once the logger has been offloaded and disconnected from the computer, the LCD will turn off automatically after 2 hours. The LCD will turn back on the next time the logger is connected to the computer.
- If the logger is recording both occupancy and light, the LCD screen will cycle between both channels every 10 seconds.
- To save battery life when the occupancy channel is enabled, the LCD will shut down if no motion is detected. Upon entering the detection zone of the sensor, the LCD will turn back on within 1 second of detection.

Setting up the Logger

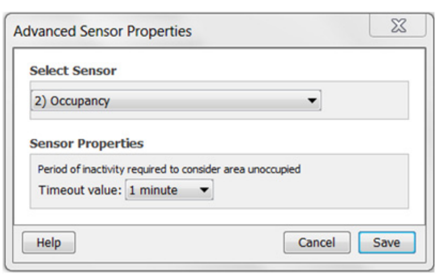
Use HOBOware to set up the logger, including configuring the sensor and selecting the start and stop logging options.

1. **Connect the logger and open the Launch Logger window**. To connect the logger to a computer, plug the small end of the USB cable into the side of the logger and the large end into a USB port on the computer. Click the Launch icon on the HOBOware toolbar or select Launch from the Device menu.



Important: USB 2.0 specifications do not guarantee operation outside the range of 0°C (32°F) to 50°C (122°F).

2. **Configure the sensor.** Type a label for the sensor if desired and select the measurement type. Both channels can be configured to log:
   - **State.** This records how long an event lasts by storing the date and time when the state of the signal changes (logic state high to low or low to high). The logger checks every second for a state change, but will only record a time-stamped value when the state change occurs. One state change to the next represents the event duration.
   - **Runtime.** The logger checks the state of the line once every second. At the end of each logging interval, the logger records how many seconds the line was in the logic low state.
3. **Set a timeout value for the occupancy sensor in the Advanced settings.** This is the amount of time the logger will wait with no motion detected before it records that the room is unoccupied. Click the Advanced button, select the Occupancy sensor, and then select the timeout value (shown below). Click Save to return to the Launch Logger window.

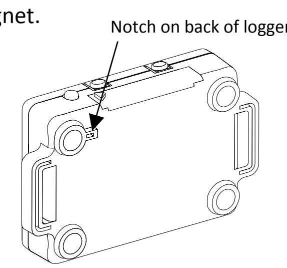


4. **Choose a calibration method for the light sensor from the Advanced settings.** The default calibration method is to calibrate from the logger using the calibrate button after the logger is launched. If you need to specify the sensitivity used for calibration, then click the Advanced button and select either a maximum or minimum level. See *Calibrating the Light Sensor* for more details.
5. **Configure optional filters as necessary.** Click the Filters button to create additional filtered data series based on the sensor configuration. Any filtered series will be automatically available upon reading out the logger.
6. **Set the units to display on the LCD screen.** Select either Time or %.
7. **If the logger is configured to record runtime, choose a logging interval from 1 second to a maximum of 18 hours, 12 minutes, and 15 seconds.**
8. **Choose when to start logging:**
   - **Now.** Logging begins immediately.
   - **At Interval.** Logging will begin at the next even interval (available when logging runtime only).
   - **On Date/Time.** Logging will begin at a date and time you specify.
   - **Push Button.** Logging will begin once you press the Start/Stop logging button for 3 seconds.
9. **Choose when to stop logging:**
   - **When Memory Fills.** Logging will end once the logger memory is full.
   - **Never (Wrapping).** The logger will continue recording data indefinitely, with newest data overwriting the oldest.
   - **Push Button.** Logging will end once you press the Start/Stop logging button for 3 seconds. Note that if you also choose Push Button to start logging, then you will not be able to stop logging until 5 minutes after logging begins.
   - **Specific Stop Time.** Logging will end at a date and time you specify.
10. **Choose whether to keep the LCD on or off.** By default, the LCD will always remain on while logging. If you select the "Turn LCD off" checkbox, the LCD will not show the current readings, status, or other information while the logger is logging. You will, however, be able to temporarily turn the LCD screen on by pressing the Start/Stop button for 1 second if you select this option.
11. **Click the Start button to launch the logger.** Disconnect the logger from the computer and deploy it using the mounting materials (see *Mounting the Logger*). After logging begins, you can read out the logger at any time (see *Reading Out the Logger* for details).

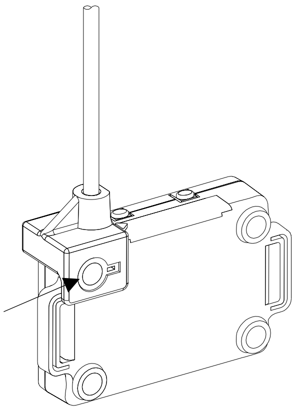
Using the Logger with the Light Pipe

An optional fiber optic attachment or light pipe (UX90-LIGHT-PIPE-1) is available for this logger. This attachment connects to the back of the logger. To install it:

1. Locate the notch in the upper left corner next to the mounting magnet.



2. Insert the black base of the attachment into the notch so that the base clips onto the corner of the logger as shown below.



Follow these guidelines when using a light pipe:

- Make sure the end of the light pipe is as close to the light source as possible.
- Maximize the signal strength on the logger LCD screen by adjusting the light pipe while looking at the signal bars (see *Calibrating the Light Sensor* for more details on signal strength).
- Be sure to secure the light pipe after the signal has been optimized.
- Do not support the logger by the light pipe.
- Be sure that the pipe is seated all the way into the bracket before deployment.

Determining Logging Duration

The logger's storage capacity and logging duration depends on the interval between occupancy or light on/off state changes. The longer the interval between the changes, the more memory is needed to store each data point. The following table shows how memory capacity is affected by the amount of time between occupancy or light changes:

Time Between Events	Approximate Total Data Points	Approximate Logging Duration (1 Year Battery Life)	Logger Part Number
1 to 15 seconds	84,650	23.51 hours to 14.7 days	UX90-005/ -006
	346,795	4.01 to 60.21 days	UX90-005M/ -006M
16 seconds to 4.25 minutes	63,488	11.76 to 187.38 days	UX90-005/ -006
	260,096	48.17 days to 2.1 years	UX90-005M/ -006M
4.26 to 68.25 minutes	50,790	150.49 days to 6.6 years	UX90-005/ -006
	208,077	1.69 years to 2.7 decades	UX90-005M/ -006M
68.26 minutes to 18.2 hours	42,325	5.5 years to 8.8 decades	UX90-005/ -006
	173,397	2.25 to 36.03 decades	UX90-005M/ -006M

Notes:

- Typical battery life is 1 year when state changes are at 1 minute or greater intervals.
- The logger can record battery voltage data in an additional channel. This is disabled by default. Recording battery voltage reduces storage capacity and is generally not used except for troubleshooting.

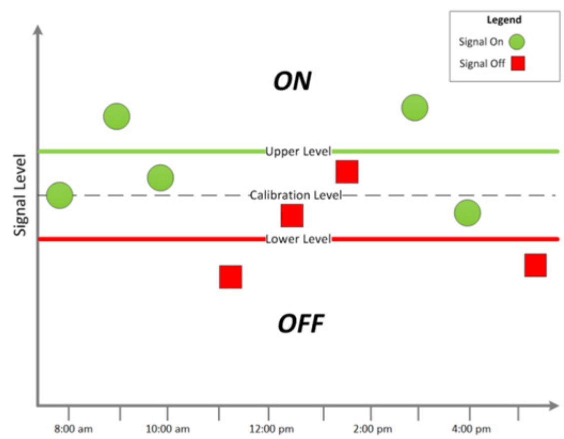
Calibrating the Light Sensor

Each time you place the logger in a new lighted environment, you should calibrate it to the light level that you will be monitoring. This ensures the logger is accurately determining when the light changes between ON and OFF states. There are two calibration methods available: auto-calibration (button calibration) or preset calibration via HOBOware.

Auto-calibration is used to calibrate the ON and OFF threshold of the logger to achieve reliable readings in an environment where ambient conditions are unknown prior to deployment or where logger light levels are variable. In the auto-calibration process, the light is measured via a built-in analog-to-digital converter and the resulting value is used to generate a calibration threshold. **Note:** Auto-calibration (button calibration) must be done at the location where the logger will be deployed.

Preset values are used when light levels are known in advance and deployment speed is critical.

The logger has a built-in hysteresis level of approximately ±12.5% to prevent the sensor from toggling between ON and OFF when the light level is near the calibration threshold. The following plot shows how the logger handles hysteresis. The logger interprets the signal, or light, as ON until it drops below the lower level of the calibration threshold. Once it switches to off, the signal will not switch back to ON until it bypasses the upper limit of the calibration level.



When auto-calibrating from the logger (button calibrating):

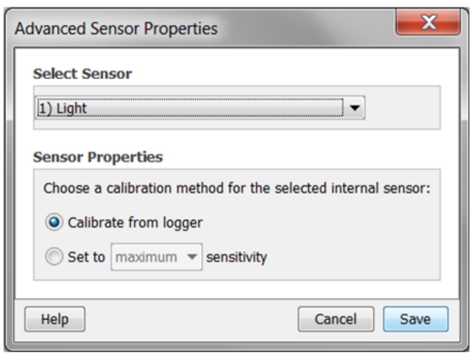
1. Deploy the logger near the light to be monitored and turn the light source on.
2. Press the Calibrate button for 1 second. The LCD screen will display the signal strength of the light. The signal strength should ideally be at least 3 bars. Orient the logger as necessary to increase the signal strength.
3. Press the Calibrate button for 3 seconds while “HOLD” appears on the LCD screen. Move your hand away from the

logger to prevent shadowing. The logger will count down to the auto-calibration and then display either "PASS" or "FAIL" after calibration is complete.

4. If the auto-calibration fails, point the sensor directly at the light source and then repeat these steps.

If you cannot manipulate the light source, you can set the calibration level in HOBOware. To do this:

1. Click the Advanced button in the Launch Logger window.
2. The lower the light level, the higher the sensitivity needs to be to record changes between ON and OFF conditions. Therefore:
   - For rooms with low light levels, such as residential environments, select "Set to maximum sensitivity," which has a threshold set to approximately 100 lux.
   - For rooms with high light levels, such as retail environments, select "Set to minimum sensitivity," which has a threshold set to approximately 500 lux.



Note: The sensor is sensitive to lights that emit high amounts of infrared radiation like incandescent and halogen bulbs. It is best to use auto-calibration when possible when monitoring on/off conditions for lights with high infrared radiation.

3. Click Save. Note that the selections will not take effect in the logger until you launch it.

Reading Out the Logger

There are two options for reading out the logger: connect it to the computer with a USB cable and read out it with HOBOware, or connect it to a HOBO U-Shuttle (U-DT-1, firmware version 1.15m030 or higher) and then offload the data files from the U-Shuttle to HOBOware. Refer to the HOBOware Help for details.

Recording Internal Logger Events

The logger records the following internal events to help track logger operation and status:

Internal Event Name	Definition
Host Connected	The logger was connected to the computer.
Started	The Start/Stop button was pressed to begin logging.
Stopped	The logger received a command to stop recording data (from HOBOware or by pushing the Start/Stop button).
Internal Calibration	The logger was calibrated via auto-calibration (button calibration).
Host Calibration	The logger was calibrated via HOBOware.
Calibration Failure	Calibrating the logger has failed.
Button Up/Button Down	The Start/Stop button was pressed for 1 second.
Safe Shutdown	The battery level dropped below 2.5 V; the logger performs a safe shutdown.

Mounting the logger

There are several ways to mount the logger using the materials included:

- Use the four built-in magnets on the back of the logger to mount it to a magnetic surface.
- Attach the Command strip to the back of the logger to mount it a wall or other flat surface.
- Use the double-sided tape to affix the logger to a surface.
- Insert the hook-and-loop strap through the mounting loops on both sides of the logger to mount it to a curved surface, such as a pipe or tubing.

Deployment Guidelines

The occupancy sensor is a pyroelectric infrared (PIR) sensor that detects variations in infrared radiation that occur when there is movement by a person (or object) that is different in temperature from the surroundings. This means the sensor can detect the motion of people by their body temperature. It may not detect a change when there is no movement or no temperature change in the heat source. It may also detect the presence of heat sources other than the human body. Do not install it where a heat source other than motion will trigger an event. Reflections from mirrors or windows can also cause unwanted events.

Protecting the logger

The logger is designed for indoor use and can be permanently damaged by corrosion if it gets wet. Protect it from condensation. If the message FAIL CLK appears on the LCD screen, there was a failure with the internal logger clock possibly due to condensation. Remove the battery immediately and dry the circuit board.

Note: Static electricity may cause the logger to stop logging. The logger has been tested to 8 KV, but avoid electrostatic discharge by grounding yourself to protect the logger. For more information, search for "static discharge" in the FAQ section on onsetcomp.com.

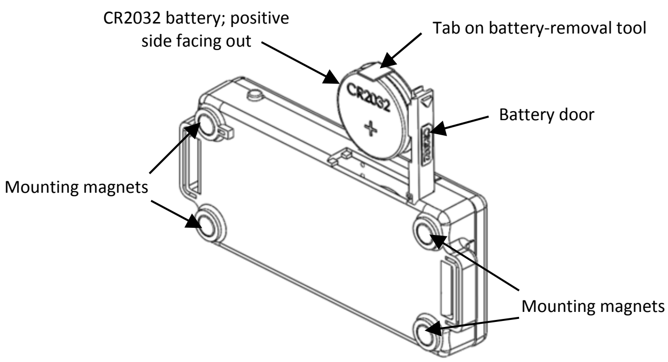
Battery Information

The logger is installed with a 3V CR2032 battery (HRB-TEMP). Expected battery life varies based on the ambient temperature where the logger is deployed, the logging interval, the rate of state changes, the frequency of offloading to the computer, number of channels that are active, and battery performance. A new battery typically lasts 1 year with a logging interval greater than 1 minute. Deployments in extremely cold or hot temperatures or a logging interval faster than 1 minute may reduce battery life. Estimates are not guaranteed due to uncertainties in initial battery conditions and operating environment.

The logger can also be powered by the USB cable when the remaining battery voltage is too low for it to continue logging. Connect the logger to the computer, click the Readout button on the toolbar, and save the data as prompted. Replace the battery before launching the logger again.

To replace the battery:

1. Open the battery door on the top of the logger.
2. Use the tab on the built-in battery removal tool inside the compartment to remove the battery.
3. Place the circular battery removal tool around the negative side of the new battery with the tab up. Insert the new battery with the positive side facing out. The LCD should display "HOBO" briefly after correctly installing the battery.



WARNING: Do not cut open, incinerate, heat above 85°C (185°F), or recharge the lithium battery. The battery may explode if the logger is exposed to extreme heat or conditions that could damage or destroy the battery case. Do not dispose of the logger or battery in fire. Do not expose the contents of the battery to water. Dispose of the battery according to local regulations for lithium batteries.

HOBOware provides the option of recording the current battery voltage at each logging interval, which is disabled by default. Recording battery life at each logging interval takes up memory and therefore reduces logging duration. It is recommended you only record battery voltage for diagnostic purposes.

HOBO®

Energy Logger

Data Logger & Modules User's Guide

onset®

Part #: MAN-H22
Doc #: 9857-F

DANGER! HIGH VOLTAGE HAZARD!

This logger can be used with sensors that may be installed in an energized electrical enclosure or on an energized conductor. Installation of sensors in an energized electrical enclosure or on an energized conductor can result in severe injury or death. These sensors are for installation by qualified personnel only. To avoid electrical shock, do not install or service these sensors unless you are qualified to do so. Disconnect and lock out all power sources during installation and servicing. Please read the user's manual for instructions and use.

Contact Information

For support, please contact the company that you bought the products from: Onset Computer Corporation or an Onset Authorized Dealer.

Onset Computer Corporation
470 MacArthur Blvd.
Bourne, MA 02532

Mailing Address:
P.O. Box 3450
Pocasset, MA 02559-3450

Phone: 1-800-LOGGERS (1-800-564-4377) or 508-759-9500
Fax: 508-759-9100
Hours of Operation: Customer Service, 8 AM to 5 PM ET, Monday through Friday, Technical Support, 8 AM to 8 PM ET, Monday through Friday

E-mail: loggerhelp@onsetcomp.com
Main Onset Web site: www.onsetcomp.com

If you purchased the products through an Onset Authorized Dealer, you can also refer to www.hobohelp.com for support information.

Table of Contents

Section 1: Introduction

This section discusses the following topics:

- Overview
- Specifications
- Key Features
- FlexSmart Modules
- Smart Sensors
- Components
- Accessories

Overview

The HOBO Energy Logger is a modular, reconfigurable data logging system used in energy and industrial monitoring applications.

The 15-channel system enables you to quickly and easily perform a broad range of monitoring applications. You can use the HOBO Energy Logger with FlexSmart™ modules, which convert signals from many types of Onset and third-party sensors. You can also use any Smart Sensor that is compatible with the HOBO Weather station or HOBO Micro Station.

Note: Although some Smart Sensors are intended mainly for outdoor use (for example, the Solar Radiation sensor), the Energy Logger is suitable for indoor use only.

Use HOBOware® Pro software to configure and communicate with the logger. HOBOware Pro allows you to customize configuration settings, launch the logger, read out the data, and plot or export the data for analysis.

The Energy Logger package includes:

- HOBO Energy Logger
- Energy Logger User's Guide
- Eight 1.5V alkaline batteries
- One miniature slotted screwdriver
- Blank label
- Rubber feet

Specifications

Operating range	-20° to 50°C (-4° to 122°F) with alkaline batteries -40° to 60°C (-40° to 140°F) with lithium batteries
Sensor inputs	Three FlexSmart multi-channel modules and up to 6 Smart Sensors (which may have multiple parameters/channels)
Sensor connectors	Six RJ-12 Smart Sensor jacks plus 3 FlexSmart module slots
Communication	RS-232 via 3.5 mm serial port or/and 9-pin D-Sub connector
Dimensions	15.6 cm x 8.4 cm x 4.6 cm (6.13" x 3.31" x 1.81")
Weight	435 g (15.23 oz) with batteries 238 g (8.33 oz) without batteries
Memory	512K nonvolatile flash data storage
Memory modes	Stop when full; wrap when full
Operational indicators	Six indicators provide logging and sensor network status
Logging interval	One second to 18 hours, user-specified interval (2-second minimum for two-channel S-FS-TRMSA operation)
Sensor excitation	12 V DC at 200 mA total, with user-programmable warmup time on a per-channel basis
Battery life	One year typical use (up to 75 mA excitation with 10-minute or longer logging Interval and 1-second warmup time)

Battery type	Eight standard AA alkaline batteries included (for operating conditions -20°C/-4°F to 50°C/122°F); optional AA lithium batteries available for operating conditions of -40° to 60°C (-40° to 140°F).
External power	Supports optional 13.6 V DC regulated AC Wall Adapter Connector. Internal batteries may remain installed. Alternatively, an automotive battery or 9-12 V DC regulated Wall Adapter may be used, but it is recommended to remove the internal batteries since they will discharge to the level of the external supply.
Time accuracy	0 to 2 seconds for the first data point and ±5 seconds per week at 25°C (77°F)
Logging mode	Immediate, timed delay, or trigger (button-push) start options; supports sampling intervals for some sensors
Data communication	Current readings while logging; read out while logging; read out when stopped
CE	CE marking identifies this product as complying with all relevant directives in the European Union (EU).

Key Features

Flexible expansion

The logger is not preconfigured. You can use any combination of FlexSmart modules (up to 3) and Smart Sensors (to a maximum of 15 channels) by plugging them in before logging begins.

Automatic detection of Smart Sensors

The logger automatically recognizes Smart Sensors. No programming, wiring, or calibration is required to set them up.

Digital network

The connections between the Smart Sensors and the logger are digital, ensuring accurate, reliable data collection and storage.

Excitation

The Analog module (S-FS-CVIA) supports optional, user-configurable sensor excitation power and warm up. The logger provides 12 V DC sensor excitation voltage up to 200 mA for transducers that require external power for proper operation. Refer to Sensor Excitation on page 20 for details.

Flexible power capabilities

The logger supports multiple battery types (alkaline, enhanced alkaline, or lithium) as well as several types of external power sources to allow for longer deployments while providing increased power for sensor excitation. Refer to External Power Sources on page 28 for details.

FlexSmart Modules

The logger is compatible with two types of FlexSmart modules, which can accommodate up to two sensors each. Up to three FlexSmart modules (in any combination) can be connected to the logger.

The **Analog Module** (S-FS-CVIA) offers configurable excitation power and can be connected to any one or two of the following sensors:

The **TRMS Module** (S-FS-TRMSA) can be connected to the following compatible AC current and potential (voltage) transformers:

For detailed information on these modules and sensors, including new modules and sensors that may have been introduced after this manual was printed, refer to the Onset website:
http://www.onsetcomp.com/solutions/products/energy

Smart Sensors

The Energy Logger can accommodate up to six Smart Sensors to monitor temperature, humidity, pressure, current, voltage, pulses, and other properties. Smart Sensors are automatically detected when logging begins, and do not require any configuration.

For detailed information on Smart Sensors, including new sensors that may have been introduced after this manual was printed, refer to the Onset website:
http://www.onsetcomp.com/solutions/products

Components

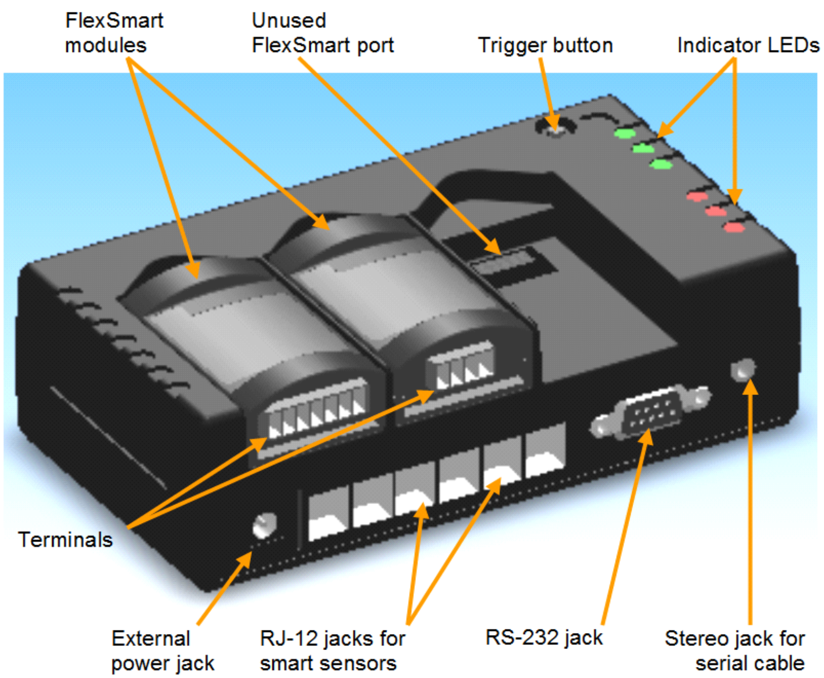


Figure 1: Components

FlexSmart Module Ports

Up to three FlexSmart modules can be installed on the logger. These can consist of any combination of Analog and TRMS modules. Third-party sensors (available through Onset) are connected to the logger through the terminals on these modules.

Trigger Button

Hold down the button for at least two seconds to manually start the logger in the field if the **Trigger** start option was selected in HOBOware Pro during launch.

Indicator LEDs

There are three green and three red status indicators. The green indicators blink to show status or activity. The red indicators blink to show that battery or memory is low, or that a sensor error has occurred. For more detailed description of the indicators, refer to Diagnostics and Troubleshooting on page 34.

Stereo Jack for Serial Cable

The serial interface cable is connected to this port to communicate with HOBOware Pro or the HOBO U-Shuttle.

RS-232 Jack

This port allows you to connect the logger via a DB9 connector instead of the stereo jack. The pinout for the logger's RS-232 connector is as follows:

Pin #	Function
1	DCD (Connected internally to 4)
2	RxD (Logger Received Data In)
3	TxD (Logger Transmit Out)
4	DTR (Connected internally to 1)
5	Signal Ground
6	NC
7	RTS (Connected internally to 8)
8	CTS (Connected internally to 7)
9	NC
Shell	Logger Chassis Ground

RJ-12 Jacks

Any combination of up to six Smart Sensors can be installed on the logger.

External Power Jack

An optional external power adapter can be connected to this port to power the logger.

Accessories

The following accessories can be used with the HOBO Energy Logger. These accessories can be purchased from an Onset Authorized Dealer, or directly from Onset Computer Corporation.

For detailed information on these accessories, including new items that may have been introduced after this manual was printed, refer to the Onset website: http://www.onsetcomp.com/solutions/products/energy

Accessory & Onset part #	Description
USB Serial Adapter Cables ADAPT-SER-USB	Allows you to connect the logger to a USB port on your computer.
Energy Logger Feet A-H22-MOUNT-1	Allows you to securely mount the logger to a panel or other surface. Includes screws.
Energy Logger Mounting Kit A-H22-DINMOUNT-1	Allows you to mount the logger to industry-standard 32 mm and 35 mm DIN rails.
Energy Logger Spares Kit A-H22-SPARES	Spare bumpers, screwdriver, and FlexSmart module connector covers.
FlexSmart Analog Module Spares Kit A-FS-CVIA-7P	Four 7-pin screw terminals and screwdriver; lets you leave a sensor attached to screw terminal for later connection to module.

Accessory & Onset part #	Description
FlexSmart TRMS Module Spares Kit A-FS-TRMSA-4P	Four 4-pin screw terminals and screwdriver; lets you leave a sensor attached to screw terminal for later connection to module.
Energy Logger AC Power Adapter P-AC-1	Allows you to power the logger using AC power, rather than batteries. (100 to 240 VAC, 50 or 60 Hz input.)

Section 2: Setup and Test

Before deploying the logger, read this section thoroughly and follow *all* of the procedures at least once. This will ensure that you are comfortable enough with the logger and with HOBOware Pro software to get the most out of your deployment. It will also verify that the logger is configured properly.

Note: Refer to the *HOBOware User's Guide* for detailed information about setup.

Requirements

You will need the following items to prepare the logger for use:

- Eight 1.5V Alkaline Batteries and small Phillips head screwdriver (for battery door); or external power source
- At least one of the following:
  - FlexSmart modules with third-party sensors and miniature slotted screwdriver
  - Smart Sensors
- Serial interface cable (plus USB serial adapter if your computer does not have a serial port)
- Computer running HOBOware Pro version 2.1.1 or greater

Steps

To set up the logger, take the following steps:

1. Insert the batteries or connect external power source.

   To install batteries, use a Phillips head screwdriver to loosen the screw on the back of the battery compartment door. Remove the door. Install eight fresh 1.5 V batteries, being careful to match the polarity marked in the battery compartment. (Refer to Selecting Batteries on page 23 for tips on selecting the right battery type for your application.) Replace the battery compartment door and tighten the screw to secure it. **Do not over-tighten the screw.**

   See Batteries on page 23 for more information.

   To use an external power source, plug the power adapter into an electrical outlet or other power source, then plug the power adapter into the external power jack. See External Power Sources on page 28.

2. Install FlexSmart modules (if applicable).

   You can install up to three FlexSmart modules on the logger. Modules may be plugged into any slot in any combination. See *Installing FlexSmart Modules* on page 11.

3. Attach the third-party sensors to the modules (if applicable).

   For information on installing the third-party sensors, refer to Modules and Sensors on page 17 as well as the instructions that came with the sensor.

4. Connect the Smart Sensors (if applicable).

   Plug up to six Smart Sensors into the RJ-12 modular jacks, or use splitters to install more than six. (Keep in mind that some Smart Sensors have more than one sensor channel.) The logger supports up to 15 sensor channels, plus the logger's own battery channel (if selected for logging).

5. Connect to the host computer.

   Use the serial interface cable (part # ADAPT-SER-USB) to connect the logger to a computer running HOBOware Pro. If your computer does not have a serial port, you can use a Keyspan™ USB serial adapter (part # ADAPT-SER-USB) to connect the logger to a USB port on your computer.

6. Access the **Launch** dialog in HOBOware Pro.

   In the Launch window, you should see a list of all the Smart Sensors and FlexSmart modules you connected to the logger.

Note: Modules and smart sensors are listed in HOBOware in ascending order by serial number regardless of their physical position within the logger.

FlexSmart Modules

Installing FlexSmart Modules

Remove the protective cap from the module connector on the logger. Align the connector on the back of the FlexSmart module with the connector on the logger, and gently press the module into place.

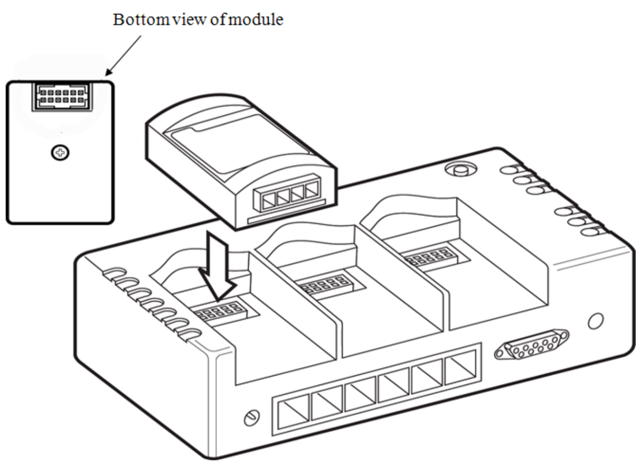


Figure 2: FlexSmart Module

Configuring FlexSmart Modules

While Smart Sensors are designed and preconfigured for specific purposes, FlexSmart modules are user-configurable to accommodate a wide range of Onset and third-party sensors. To take advantage of this adaptability, HOBOware Pro lets you configure these modules at launch time, or create and save different configurations to be loaded into the modules whenever needed.

If you connected only Smart Sensors, skip ahead to the next topic, "Launching the logger."

1. Access the **Configure Channel** dialog in HOBOware Pro.

   From the **Launch** window in HOBOware, double-click a module name to expand it, then select a module channel and click **Configure**.

2. Load an existing configuration, if available.

   HOBOware Pro may already have a default configuration for your sensor. Click the **Load** button to select an existing configuration for the sensor.

3. Review the loaded configuration, or create a new one.

   The **Configure Channel** dialog allows you to create or change the channel name, scaling parameters, and other items. (Refer to the *HOBOware User's Guide* for details.)

4. Review or set excitation power, if applicable.

   If this is an Analog module, make sure that the excitation power settings are correct for the intended sensor.

5. Save the new or changed configuration.

   Skip this step if you are using a default configuration without any changes.

6. Click **Configure** to complete the configuration.

   Repeat these steps for each channel of each module.

Launching the Logger

Once all Smart Sensors have been connected and FlexSmart modules have been configured, access the Launch window in HOBOware Pro and take the following steps:

1. Select the correct battery type (alkaline or lithium).

   If the battery type is not set correctly, the batteries will not report their power accurately.

2. Review the list of channels.

   Make sure all of your sensors and modules are listed in the Launch window in HOBOware Pro. The FlexSmart modules and Smart Sensors are listed in ascending order by serial number. If more than 15 data channels are connected, the devices with the higher serial numbers will be ignored and their data will not be recorded. The logger can only record 15 data channels at a time.

3. Log battery voltage (Optional)

   If you are using excitation power, you should also log the battery voltage. This channel does not count towards the 15-channel limit.

4. Wrap (Optional)

   The Energy Logger will stop logging when its memory is full, or you can enable wrapping. With wrapping enabled, when the logger's memory fills up, the newest measurements will overwrite the oldest measurements.

5. Pre-set Data Assistants (Optional)

   Configure pre-set Data Assistants as desired. See the *HOBOware User's Guide* for details.

6. Review other launch settings.

   Select logging and sampling intervals, and indicate whether you want to begin logging now, wait for a timed delay, or a trigger start. Refer to the *HOBOware User's Guide* for more information about these settings.

7. Click **Launch.**

   Depending on the option you select, the logger may start automatically (either immediately or at a specified time), or you may start it manually by pressing the **Push to Start** button on the logger.

Checking Logger Status

You can verify logger status by looking at the indicator lights on the logger. The LEDs blink to let you know if the logger is waiting for a delayed or button start, or if the logger is already logging. Other LEDs blink to warn you when battery power or memory is running low, or if there is a sensor error. Refer to Indicator LED Behavior on page 34 for details.

You can get more detailed information about battery power, sensor readings, and memory in HOBOware Pro at any time, whether the logger is logging or not. Refer to the *HOBOware User's Guide* for details about the Status window.

Note: In HOBOware Pro, battery capacity is reported differently depending on the type of batteries being used. For alkaline batteries, the status is displayed as a percentage of the capacity remaining.

For lithium batteries, capacity is listed as “Good” for 25-100% capacity remaining, or “Empty” for 25% or less capacity remaining. This is necessary because lithium battery voltage does not vary much until the batteries are nearly depleted. Because of the uncertainty in capacity, you may wish to start each deployment with fresh lithium batteries that you know are at 100%, rather than rely on old ones.

Stopping the Logger

If wrap is not enabled, the logger automatically stops recording data when the memory is full. You can also stop the logger manually at any time by using the **Stop** command in HOBOware Pro.

Once the logger has stopped, the data remains in the logger until the next launch.

Reading out Data

Use HOBOware Pro to read out data from the logger. Reading out copies data from the logger to your computer, allowing you to save the data in a .dtf file and view the plot.

You can read out while the logger is recording data, or after the logger has been stopped. Refer to the *HOBOware User's Guide* for details about reading out, saving, and displaying data.

Verifying Logger Operation

It is a good idea to quickly test the logger before each deployment, especially if the logger has been stored unused for a long period. To test the logger, take the following steps:

1. Set up the logger (attach sensors, etc.) and start HOBOware Pro.
2. Access the Launch window and verify that HOBOware Pro detects all of the connected modules and sensors.
3. Enter a logging interval of a few seconds so that your test will yield enough data to look at, and select the logger's internal battery channel. Make sure the logger is configured to start logging immediately upon launch.

   Important: If you are using both channels of a TRMS module, you must select a minimum 2-second logging interval. If all TRMS modules are configured for single-channel use, you can use a 1-second logging interval.
4. If you are using sensor excitation, configure it for each FlexSmart Analog module channel. Sensors purchased from Onset include sensor connection instructions, including warmup time (if required). For sensors not supplied by Onset, consult the sensor manufacturer's datasheet for warm up time requirements.
   - Many sensors specifications assume that the sensor will be powered continuously, but may be capable of switched operation to conserve battery life. You may need to experiment to determine the best warm up time for rated transducer accuracy.
   - The Energy Logger disables excitation when the battery pack voltage falls to approximately 6.8V (0.85 volts per cell). The batteries are essentially dead at this point and should be changed. The logger will continue to log, but data for channels using excitation will be invalid.

5. Click **Launch** to start the logger.
6. After a couple of minutes, read out the logger. (Answer **Yes** when prompted to stop the logger.)
7. Make sure the data appears normal for all sensors.

Section 3: Modules and Sensors

This section provides details on working with modules and sensors.

Adding and Removing Modules and Sensors

Whenever possible, it is best to add and remove modules and sensors between deployments – after stopping the logger and reading out data, but before relaunching. However, circumstances may require that you add or remove a module or sensor at some other time.

If you **add** a module or sensor while the logger is recording data, the module or sensor will be ignored. Logging will continue normally for the other channels.

You may attach modules and sensors at the following times:

- Any time between deployments, when the logger is stopped.
- While you are configuring the launch parameters in HOBOware Pro. Click **Refresh** to update the **Logging Duration** and see the new module or sensor added to the list of sensors.
- After you have launched the logger, but before logging has begun (i.e. when the logger is waiting for a delayed or button start). Note that adding modules or sensors will cause the logging duration to be shorter than the duration that was displayed in the Launch window.

If you **remove** a module or sensor while the logger is logging, the **Sensor Fail** indicator will blink when the next logging interval is reached, and the logger will record erroneous data for that channel. This is true even if you immediately connect another sensor of the same type in the same port. If you want to change sensors – even sensors of the same type – you must stop the logger, read it out, swap the sensors, and then relaunch.

Smart Sensor Cables

The logger can work with a maximum total of Smart Sensor cable lengths up to 100 meters (328 feet), as measured from the logger connection point to the electronics embedded in the individual cables. Optional Smart Sensor extension cable lengths must also be included in the total.

This limitation applies to Smart Sensor cables only. The lengths of other cables, such as those connected to FlexSmart modules, do not need to be included in this total.

Analog (CVIA) Module

The Analog module (S-FS-CVIA) is an easy-to-configure, flexible DC signal-conditioning module for the HOBO Energy Logger. This two-channel module can accept (and provide excitation power to) a wide range of Onset and third-party sensors with 0-0 V or 0-20 mA output, including devices with 4-20 mA current loop interface, and sensors with 0-2.5, 0-5, and 0-10 V DC output.

The Analog module features input protection and signal filtering, as well as delta-sigma A/D conversion and factory calibration. This module features extremely low-power operation, resulting in long battery life for unattended data logging applications. Precision electronics provide ±0.25% accuracy from 50 mV to full scale (FS).

Sensors connected to this Analog module can be configured in HOBOware Pro software. Configuration options include channel names, scaling parameters, and excitation power. Sensors are connected to the module via a seven-pin Phoenix-style detachable screw terminal connector.

Functional Block Diagram

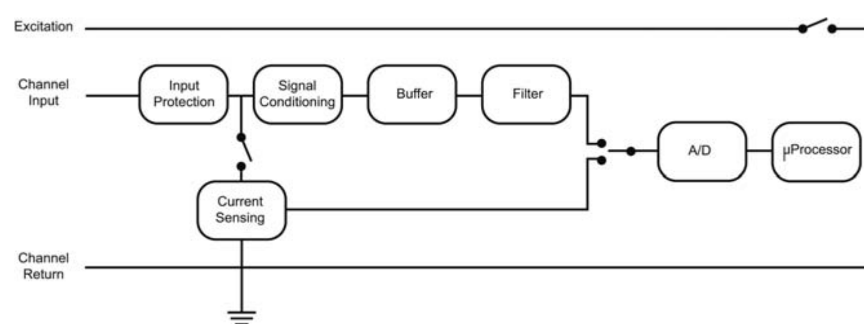


Figure 3: Analog Module - Functional Block Diagram

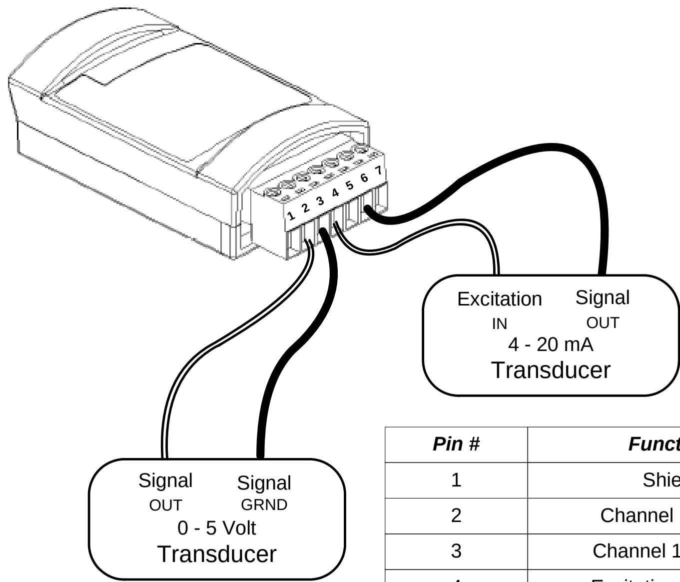
Connecting Sensors to the Analog Module

Insert the Phoenix-style screw terminal connector into the connector on the end of the module.

Note: The Analog module is a single-ended device. Pins 3 and 7 are connected to signal ground and to each other.

Refer to the sensor documentation for terminal connection details and use the pinout diagram below to connect a two- or three-wire sensor or transducer to the module’s terminals. To make the connection, loosen the screw for each pin on the connector, insert the appropriate wire, and tighten the screw.

The following example illustrates typical connections for a voltage sensor, and a current sensor that requires excitation:



Pin #	*Function*
1	Shield
2	Channel 1 Input
3	Channel 1 Return
4	Excitation Voltage
5	Excitation Return
6	Channel 2 Input
7	Channel 2 Return

Figure 4: Voltage Sensor Connections

Tip: Always refer to your sensor documentation for terminal connection details.

Once the sensors are connected, install the Analog module into any of the three module slots on the logger.

Use the provided label to identify a module/sensor combination to aid in determining sensor placement and cable routing when in the field.

Configuring Channels on the Analog Module

Each channel of the Analog module is individually configurable to accept a wide range of sensors. That means that each channel can be configured to measure either current or voltage, and the collected data can be scaled to produce meaningful results that are consistent with the properties being measured.

Use HOBOware Pro to configure each channel at launch time, or create and save different configurations to be loaded into the modules whenever needed. A channel configuration consists of a channel name, measured property name, scaling parameters, and excitation information, if applicable. Refer to the *HOBOware User’s Guide* for details.

Verifying Operation

When logging begins, the logger will acquire and store measurements from the sensors attached to the module. When the module is functioning correctly, the **Active** indicator on the module blinks once per logging interval for each configured channel to indicate that a successful measurement has been made.

Sensor Excitation

Sensor excitation is a voltage output provided by the logger to power a sensor that is connected to it. This power may be needed because the sensor is not self-powered, or because the sensor’s power capacity cannot support a long deployment.

When sensor excitation is required, the logger can provide 12 V DC sensor excitation voltage up to 200 mA total for transducers that require external power for proper operation. The excitation voltage has a programmable warm up time and is controlled by the FlexSmart Analog module. Excitation is controlled on a per-module basis.

Excitation power can drastically reduce logger battery life. If your sensor does not require it, you should not include it in the channel configuration.

If you do need to use it, carefully select the sensor excitation mode that best meets your needs. Two modes are available:

- **Warm up mode** – The logger supplies excitation power for a brief, user-programmable period prior to each measurement. This mode allows you to select the minimum warm up time needed to allow for sensor stabilization, while conserving the logger's battery power. For example, if you specify a warm up time of one second and set the **Logging Interval** in the logger to one minute, the logger will power the external sensor for one second, log a measurement, and then turn off the excitation power for the next 59 seconds. The warm up time can be up to 120 seconds.

  Note: If the warm up time selected is greater than the logging interval selected, the logger will interpret the excitation mode as continuous.

- **Continuous mode** – The logger supplies constant excitation power to the sensor for the entire duration of the deployment. This mode will result in the shortest battery life. Continuous mode is required if the sensor needs more than two minutes of warm up time. If you need to provide continuous excitation to a sensor, you should consider backing up your batteries with an external power source. Refer to External Power Sources on page 28 for details.

Important: When using excitation power, always enable the logger's internal battery channel at launch. If the battery becomes too low to provide excitation power, excitation power is turned off, but logging continues as long as the battery can power the logger. This will cause the further readings on that channel to become inaccurate. If you are logging the internal battery channel when this happens, an "Excitation Off" event will be shown in your datafile to mark the point at which excitation power was disabled. (If you do not log the internal battery channel, you will not have anything in your datafile to identify the point beyond which the data might be inaccurate.)

Working with Channels

The Energy Logger can log up to 15 data channels (not including the internal battery channel). This includes all FlexSmart module channels, plus each of the Smart Sensor channels (note that some Smart Sensors may have more than one channel). If you have more than 15 channels connected, some of the sensors will be ignored. You should remove any Smart Sensors that will not be used in the deployment, and disable any module channels that are not needed.

- FlexSmart modules have two channels. If you want to log only one channel, you can disable the unused channel on the Launch window in HOBOware Pro. Refer to the *HOBOware User's Guide* for details.

- If you connect a Smart Sensor that has multiple channels (such as temperature and relative humidity), all of its channels will be logged. There is no way to disable them.

Section 4: Batteries and External Power

The HOBO Energy Logger requires eight 1.5V AA batteries. The logger is shipped with eight alkaline batteries, and is also compatible with enhanced alkaline batteries and lithium batteries (Li/FeS_2).

An external power source can reduce or eliminate the need for internal batteries in applications that have readily available AC power, or require more current and/or longer deployments than the logger's internal batteries can support. See External Power Sources on page 28.

Selecting batteries

Onset recommends alkaline batteries for most applications because they are inexpensive, can provide more accurate battery status readings in HOBOware Pro, and last longer than similar lithium batteries at moderate temperatures.

However, some applications or environments are better suited to other types of batteries. Refer to the following table to determine which type of battery you should use.

Battery type	Considerations for use
Alkaline	These are best for most applications at moderate temperatures. Alkaline batteries also work in temperatures ranging from 40° to 50°C (104° to 122°F) and from -20° to 0°C (-4° to 32°F), but may not perform as well as lithium batteries at these temperatures. At temperatures lower than -20°C (-4° F) and higher than 50°C (122°F), alkaline batteries are not suitable. Use lithium batteries instead.
Enhanced alkaline (such as Energizer® E2 or Duracell® Ultra)	Consider these for applications with higher sensor excitation requirements and moderate temperatures. These batteries are specifically designed for high-current use. For low-current applications, however, they offer little improvement.

Battery type	Considerations for use
Lithium (Li/FeS_2)	Lithium batteries last longer than alkaline batteries in applications with extreme or varying temperatures (below 0°C/32°F or above 40°C/104°F). They also outperform alkalines in deployments with high sensor excitation currents (>100 mA) or long warmup times. Lithium battery voltage does not vary much until the batteries are nearly depleted. Because of the uncertainty in capacity, you may wish to start each deployment with fresh lithium batteries that you know are at 100%, rather than rely on old ones.

Important: Do not use any other type of battery, such as carbon zinc (“heavy duty”) or rechargeable batteries. These batteries will not perform well and will not report their battery status accurately in HOBOware Pro.

WARNING: Fire, Explosion, and Severe Burn Hazard. Do not mix battery types, either by chemistry or age; batteries may rupture or explode. When replacing the batteries, read and follow their disposal instructions; dispose of lithium batteries according to local regulations. Do not dispose of batteries in fire. Never attempt to recharge a lithium or alkaline battery. Do not heat the batteries above 185°F (85°C). Do not mutilate or rupture the battery housing. Lithium batteries may explode if the logger is exposed to extreme heat or conditions that could damage or destroy the battery case. Do not expose the contents of the battery to water.

Battery Life

Battery life will vary with the following factors:

- Sensor excitation current and warm up time (most important factor)
- Logging interval (and sampling interval, if applicable) selected
- Number of sensors being used

- Battery type
- Operating environment (e.g., temperature)

The following graph can help you estimate how long batteries will last (the run time) at different logging intervals and excitation currents with a warm up time of 30 seconds.

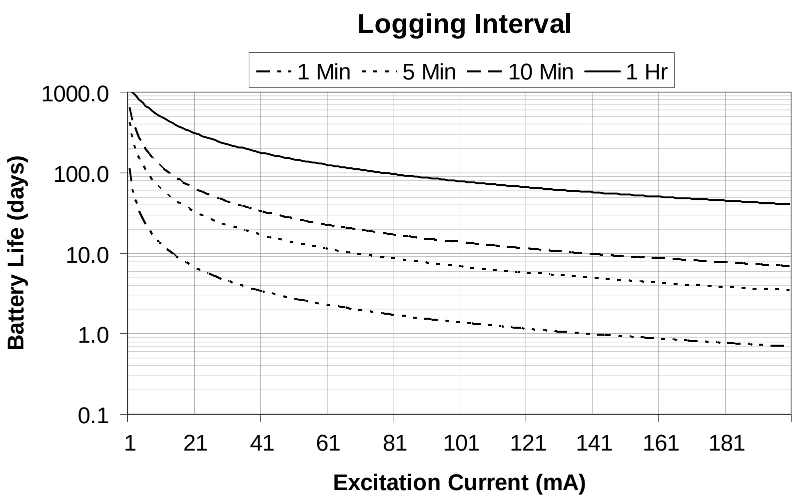


Figure 5: Battery Life

Note: This graph assumes that standard alkaline batteries and three FlexSmart modules are being used.

This graph was generated from a spreadsheet that can estimate battery life for varying parameters. Contact Onset Technical Support for more information.

Maximizing Battery Life

- Batteries are inexpensive compared to the cost of a new logger or a missed logging opportunity. If you suspect that batteries are damaged or run down, replace them immediately to prevent leakage or logger malfunction.
- When launching the logger in HOBOware Pro, do not set a **Sampling Interval** unless you have sensors that support measurement averaging. Only the following Smart Sensors and input adapters support measurement averaging:

  - 12-bit Temperature S-TMB-M0XX
  - 12-bit 4-20 mA Input Adapter (S-CIA-CM14)
  - 12-bit Voltage Input Adapter (S-VIA-CM14)
  - Photosynthetically Active Radiation (PAR) S-LIA-M003
  - Silicon Pyranometer (Solar Radiation) S-LIB-M003

  Note: Although some Smart Sensors are intended mainly for outdoor use (for example, the PAR and Solar Radiation sensors), the Energy Logger is suitable for indoor use only.

- If you are using excitation voltage, select the shortest warm up time needed for the sensor.
- Verify that the batteries' "Use Before" date is at least two years from the current date.
- Alkaline batteries will lose up to 10% of capacity per year if they are sitting on a hot shelf. They can lose 50% or more of their capacity if exposed to heat repeatedly (for example, stored on a car dashboard). Keeping batteries in the refrigerator can reduce self-discharge to 1 to 2% per year, but you must prevent condensation from forming on the batteries.
- Use new batteries if you expect the deployment to require a substantial portion of battery life.

Replacing Batteries

Fresh batteries are cheap insurance for extended deployments or high-draw applications when using an external power source is not feasible.

- Before replacing batteries, always read out the logger to prevent data loss.
- Replace batteries at least once a year to prevent loss of data.
- Replace batteries more often if you are using sensor excitation.

To replace batteries:

1. Select the type of batteries you will use and obtain eight fresh, new batteries of the same type. For more information on

selecting the type of batteries to use for your application, refer to Selecting batteries on page 23.

2. Using a Phillips head screwdriver, loosen the screw on the back of the battery compartment door. Remove the door.

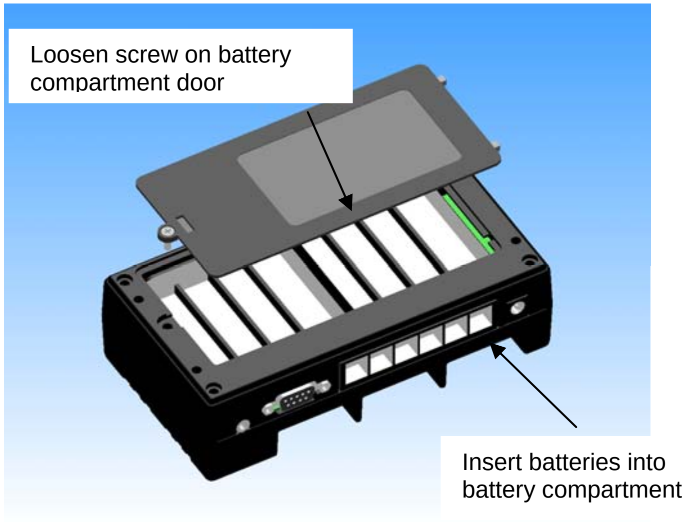


Figure 6: Replacing Batteries

3. Remove the used batteries and dispose of them properly.
4. Install eight new 1.5 V AA batteries, using care to match the polarity marked in the battery compartment. **Do not mix battery types.**
5. Position the battery compartment door in place and tighten the screw to secure it. **Do not over-tighten the screw**.

Recovering Data from a Logger with Dead Batteries

The logger uses very durable, high-capacity Flash memory. With this memory, data is retained even when the batteries are dead or removed.

If the logger stops recording data because the batteries are dead, you can recover the data that has been recorded. Simply replace the batteries and then read out the data from the logger as usual.

Important: Do not relaunch the logger until the data has been recovered. If, after changing the batteries, you are still unable to read out your

logger, contact the vendor that sold it to you. It may be possible to retrieve the logged data.

External Power Sources

An external power source can reduce or eliminate the need for internal batteries in applications that have readily available AC power, or require more current and/or longer deployments than the logger's internal batteries can support. The logger can operate on a DC input voltage from several external sources including:

- Standard 12 V automotive/motorcycle type battery
- Sealed lead-acid (SLA) type 12 V battery (used in uninterruptible power supplies and emergency lighting systems)
- External alkaline/lithium battery packs
- Optional AC power adapter (Onset part # P-AC-1)

There are two ways you can use an external power source:

- **Battery eliminator mode -** In place of the internal batteries. In this mode, the logger can operate on a DC input voltage ranging 8 V – 15 V.
- **Battery backup mode -** To conserve the internal batteries as an automatic back-up supply if the external supply should fail, similar to an uninterruptible power supply. To do this, you must provide a DC input voltage **greater than** that of the internal batteries. Thus, a DC input voltage of 13.6 V – 15 V is required for proper operation.

External Power Adapter Specifications

- Able to deliver 750mA
- Positive outer sleeve
- 2.1 mm center pin diameter
- 5.5 mm outer sleeve diameter
- 10 mm outer sleeve length

Section 5: Maintenance

This section describes general maintenance activities for the HOBO Energy Logger.

General Maintenance Schedule

Regular maintenance of the logger is essential to ensure the accuracy of recorded measurements. The logger is primarily intended for indoor use. It can be damaged by many environmental conditions, such as moisture, airborne contaminants, vibration, and tampering. Performing regular maintenance checks allow you to:

- Verify that the logger is logging data and functioning as you expect
- Identify damage
- Minimize the impact of any existing damage

The following table lists maintenance activities and how often they should be performed:

Activity	Frequency
Inspect logger housing and cables	Each use.
Verify sensor accuracy	Refer to the sensor manufacturer’s manual for information on how often to verify sensor accuracy.
Clean the logger	As needed.
Replace the batteries	At least once a year, or before any deployment that requires many sensors, excitation, etc. or is scheduled for an extended deployment.
Verify logger operation	Before each deployment.

Inspecting the Logger Housing and Cables

Periodically perform a visual inspection of the logger. Verify that the logger housing is free of visible damage, such as cracks, and that it is clean.

Also ensure that cables and wires are free of damage, such as cracks, cuts, and splits; are fastened securely, free of corrosion and in good condition.

Verifying Sensor Accuracy

Onset recommends that you test most Smart Sensor accuracies once a year. For details on verifying sensor accuracy, refer to the documentation included with each sensor. For third-party sensors (even those supplied by Onset), refer to documentation provided by manufacturer.

For a fee, Onset can verify the accuracy of any sensor. It may be possible to recalibrate some sensors. Contact Onset Technical Support for details.

Cleaning the Logger

The logger does not require specialized cleaning; however, if it is deployed in a dusty or grimy location, you should wipe it down with a damp cloth occasionally. This will prevent dirt from interfering with sensors.

Section 6: Reference

Time Accuracy

When you launch a logger, its clock is set by the host computer's time and time zone offset from UTC. (UTC, or Coordinated Universal Time, is similar to Greenwich Mean Time.) The time zone offset makes it possible to determine objective, non-local time. This prevents conflicts and confusion when you relaunch a logger with a shuttle that may have been launched in a different time zone, or before a Spring or Fall time change.

Once the logger is logging, it will keep fairly accurate time. However, the following may cause errors with time reporting.

- **Host clock error.** The most likely source of error is an incorrect time, or time zone setting, on the computer that launched the logger. Make sure the clock on your computer is set to the correct date and time before launching the logger. One accurate resource is http://www.nist.time.gov.
- **Launch time loss.** The logger may lose up to two seconds when it is launched. This is a one-time error that occurs as part of the start-up sequence and cannot be avoided.
- **Clock drift.** The logger's long-term time accuracy is related to ambient temperature. At 25°C (77°F), the worst-case error is ±8 parts per million (PPM), or about 5 seconds per week. The error increases as the temperature deviates from 25°C, as shown in the graph below. At a constant temperature of -20°C, the logger time error could be as much as 35 PPM (21 seconds per week).

The following graph shows the worst-case time error.

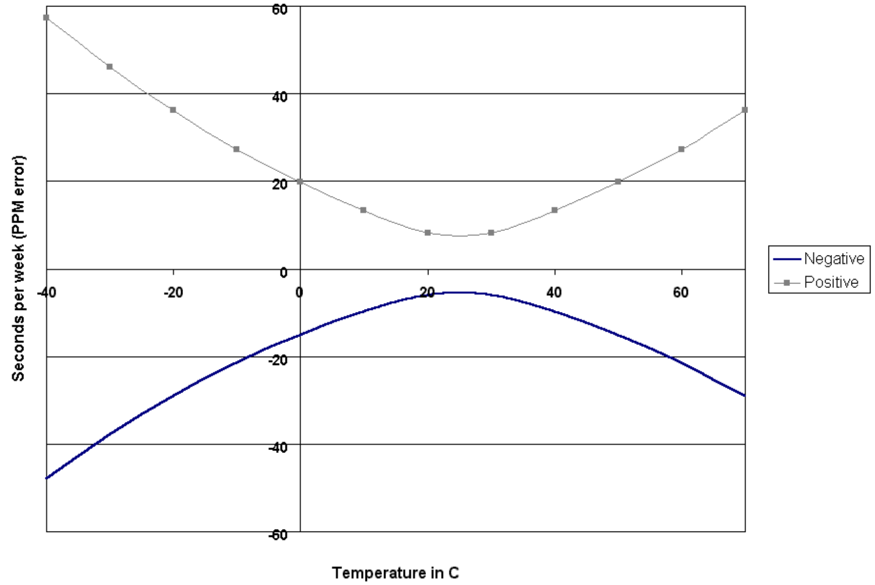


Figure 7: Worst-case Time Error

Resetting the Logger's Clock

Reading out the logger and relaunching it will reset the logger's clock. This is useful when your logger has been running for a while and its clock needs to be reset. Make sure the computer clock is set accurately before relaunching.

1. Exit HOBOware Pro.
2. Correct the computer's clock.
3. Restart HOBOware Pro.
4. Read out the logger, if you have not done so already.
5. Relaunch the logger.

Memory

The logger contains 512K bytes of very durable, high-capacity, non-volatile Flash memory, which stores data even if power runs out. This allows for data retention even when the batteries become depleted or are removed.

Up to 10K of this memory is used to store the launch configuration and deployment notes, leaving at least 502K bytes for data storage. HOBOware Pro automatically estimates how long the logger will record data before the memory fills up, based on the logging interval and the number and type of sensors connected. This is called the **logging duration**.

Adding sensors or logging the internal battery channel decreases the logging duration; increasing the logging interval increases the logging duration.

For most applications, it is battery life and not memory capacity that limits the logging duration. The following table shows the expected run time for several logging intervals based on the total number of bits in place, which is determined by adding together the bits per sample for each sensor measurement parameter in your system. For example, a HOBO Energy Logger with the following sensors is using 56 total bits.

Sensor		**Bits per Sample**		**Total bits**
1 temperature sensor	X	8	=	8
1 wind speed sensor	X	16	=	16
2 temperature sensors	X	16	=	32
Total number of bits				56

At a logging interval of 5 minutes, the logging duration for a logger using 56 bits would be approximately 250 days. (Refer to the sensor manual to determine the number of bits each type of sensor uses.)

Section 7: Diagnostics and Troubleshooting

This section lists some symptoms and tips to help you confirm correct operation of your logger, and help you diagnose possible problems. It discusses the following diagnostic and troubleshooting topics:

- Indicator LED behavior
- Testing the logger
- Problems and solutions

Indicator LED behavior

The indicator LEDs can provide helpful clues as to what the logger is doing, especially when it is not behaving as expected.

Note: The indicators are very faint under direct sunlight or bright fluorescent lighting. If no indicators appear to be blinking, shield the logger from the light and check the indicators again.

Push to Start (Green)

If you have launched the logger with the **Trigger** start option, this indicator will continue blinking and will not record any measurements until you press and hold the **Push to Start** button on the logger for at least two seconds. You can add and remove Smart Sensors and FlexSmart modules while this indicator is blinking.

Delayed Start (Green)

If you have launched the logger with an **At Interval** or **Delayed** start option, the indicator will continue blinking and the logger will not record measurements until the defined start date/time. You can add and remove Smart Sensors and FlexSmart modules while this indicator is blinking.

Logging (Green)

This indicator blinks every two seconds while the logger is recording data from sensors. Sensors must not be added while this indicator is blinking.

If this indicator is not blinking when you believe it should, make sure the logger has been launched. If you configured the logger to launch with a delayed or interval start, check the date and time you selected and make sure the **Delayed Start** indicator is blinking. If you configured the logger to launch with the **Trigger** start option, press and hold the **Push to Start** button on the logger until all the indicators flash at once (at least two seconds).

Memory Low (Red)

If the logger was launched with wrapping disabled, this indicator blinks when less than 25% of memory remains for saving data. The logger will continue to run until all memory is used.

If the logger was launched with wrapping enabled, this indicator should not blink.

Battery Low (Red)

This indicator blinks when battery power is at less than 25% capacity, or if the batteries are installed improperly. The logger will continue logging until the batteries are dead; however, you should read out the data and replace the batteries as soon as possible, before the batteries die, and then relaunch the logger. Or, attach an external power source if possible.

If this indicator continues to blink even after you have replaced the batteries:

- Check that the batteries are installed properly. If the polarity of any of the batteries is incorrect, this indicator will blink.
- Make sure you are using the correct battery type. The logger uses eight 1.5 volt AA alkaline or lithium batteries. The battery type must be specified correctly on the Launch Logger dialog for the correct battery status to be reported.
- Make sure all batteries are of the same type - either all alkaline, all enhanced alkaline, or all lithium. Never mix battery types.
- Check the battery expiration date. Verify that the expiration date is at least two years from the current date. Batteries can lose significant capacity if stored at elevated temperatures.
- Check the voltage of the batteries with a voltmeter. Alkaline batteries should be at least 1.5 V per cell when new; fresh lithium batteries should be 1.6 V per cell.

Sensor Fail (Red)

This indicator blinks when there is or has been a FlexSmart module or Smart Sensor communication failure.

Note: If the **Sensor Fail** indicator is blinking, you should read out the logger, investigate the problem, and then relaunch the logger.

- If the **Sensor Fail** indicator is blinking in conjunction with the **Logging** indicator, there was a communication failure, but the system has recovered. There may be an intermittent problem. Try checking the FlexSmart modules and Smart Sensors one at a time to make sure they are all communicating. If you find a bad module or sensor, or if no module or sensor communicates, contact your Onset Authorized Dealer or Onset Technical Support.
- If the **Sensor Fail** indicator is the only one that is blinking, at least one FlexSmart module or Smart Sensor is currently not communicating. You should investigate this problem immediately. Look for a loose connection, which could cause bad electrical contact with a module or sensor. If found, remove the offending module or sensor and check its wires and connector for damage and/or signs of moisture.

Problems and Solutions

Problem	Solution
No status indicators are blinking	The indicators are very faint under direct sunlight or bright fluorescent lighting. If no indicators appear to be blinking, shield the logger from the light and check the indicators again. Check the status in HOBOware Pro: • Make sure the batteries are not dead. Batteries should have at least 1 volt per cell. • The memory may be full. Read out the logger and relaunch. • The logger may not have been launched.

Problem	Solution
Individual modules or sensors are not found, or are missing in HOBOware Pro's Launch Logger dialog	If a FlexSmart module or Smart Sensor is removed and then immediately reconnected, it may not be detected, and therefore will not appear on the Launch Logger dialog. Click the **Refresh** button on the Launch Logger dialog. Check for a loose connection between the module or sensor and the logger. Make sure you have not exceeded 100 meters (328 ft) of network cable for all Smart Sensors.
No modules or sensors appear in HOBOware Pro's Launch Logger dialog	Remove all modules and sensors except one, click **Refresh,** and see if the module or sensor appears on the Launch Logger dialog. Continue to remove and reconnect modules and sensors one at a time until you identify the culprit. If you find the bad module or sensor, or if none of the modules or sensors communicates, contact your Onset Authorized Dealer or Onset Technical Support.
Batteries die prematurely	Check for excessive moisture or contamination in the logger enclosure. Severe and/or repeated condensation in the logger enclosure can lead to short circuits and battery failure. It may be necessary to place the logger in an additional weatherproof case with desiccant inside the enclosure to prevent condensation. Make sure that both the logging and sampling intervals are set for at least one minute or greater. Fast sampling and logging intervals (shorter than one minute) will rapidly deplete the battery. For more information, refer to "Maximizing battery life" on p. 25. Check for damaged wiring and malfunctioning modules and sensors. Damaged cables or connectors can result in complete or partial short circuits that will rapidly drain batteries.

Problem	Solution
Datafile contains errors	If you are missing data for a particular module or sensor, check that it was properly installed and configured. Remove and reconnect the module or sensor, and check the status in HOBOware Pro to verify that it can report accurate readings. If you find that it is not communicating, it may be damaged. Contact your Onset Authorized Dealer or Onset Technical Support.
Excitation power stops working	The batteries have dwindled to 6.8 V while excitation was in use. The batteries are nearly dead and must be changed.
Datafile cannot be opened	In rare circumstances, the datafile may have become corrupted. Read out the logger again and try opening the file again. If that does not work, contact your Onset Authorized Dealer or Onset Technical Support.
Logger is not found	Check and replace the batteries, and reconnect the logger. Check communication cable connections. Review the Communication preferences in HOBOware Pro. Check the computer's COM port/USB settings.

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Onset Computer Corporation
470 MacArthur Blvd.
Bourne, MA 02532

Cottonwood Meadows Survey

Apt. #___

1. **How many waking hours per day do you spend in your home during the SUMMER?**

____ 1 – 5 hours
____ 6 – 9 hours
____ 10 – 16 hours
____ 17+ hours

2. **How many waking hours per day do you spend in your home during the WINTER?**

____ 1 – 5 hours
____ 6 – 9 hours
____ 10 – 16 hours
____ 17+hours

3. **Which area of the home do you spend the most time in during waking hours during the SUMMER? (circle one)**

Bathroom Bedroom Closet Kitchen Dining Area Living Area

4. **Which area of the home do you spend the most time in during waking hours during the WINTER? (circle one)**

Bathroom Bedroom Closet Kitchen Dining Area Living Area

5. **Are there any periods of the year when you are away from home for long periods of time, such as vacations or extended travels etc.? When?**

____

6. **Are there any periods of the year when you have extended house guests or more occupants in the residence? When?**

____

7. **How satisfied are you with the lighting in the rooms of your home?**

	Not Satisfied	Somewhat Satisfied	Neutral	Satisfied	Extremely Satisfied
Bathroom					
Bedroom					
Closet					
Kitchen					
Dining Area					
Living Area					

8. **Rank the top three criteria (1–3) that are most important to you when purchasing lighting products, 1 being the most important consideration, then 2, then 3.**

_____ Lifetime (how long it will last)
_____ Price
_____ Light color (“warm white,” “cool white,” etc.)
_____ Light distribution
_____ Brightness
_____ Energy efficiency
_____ Lower energy bills
_____ *Other:*________________________

9. **If you could improve the lighting in one area of your home, which area would it be?**

_____ Bathroom
_____ Bedroom
_____ Closet
_____ Kitchen
_____ Dining Area
_____ Living Area

10. **What would you improve?**

____

11. **Name one task you frequently do in your home that requires high-quality lighting:**

____

12. **How satisfied are you with the current lighting you have for that task?**

_____ Not satisfied
_____ Somewhat satisfied
_____ Neutral
_____ Satisfied
_____ Extremely satisfied

13. In your experience with lighting, which of the following issues has bothered you most? Select one.

____ Cost (too expensive)
____ Early failure
____ Light color
____ Audible noise (humming or buzzing)
____ Slow start time
____ Flicker
____ *Other:* ______________________________

14. What is your gender?

____ Male
____ Female

15. What is your age?

____ 35 – 44 years old
____ 45 – 54 years old
____ 55 – 64 years old
____ 65 – 74 years old
____ 75 – 84 years old
____ 85 years or older

16. Which of the following best describes your current employment status?

____ Retired
____ Unemployed
____ Employed Full Time
____ Employed Part Time
____ Self-Employed
____ Prefer not to answer

THANK YOU FOR YOUR INPUT!

CALIFORNIA LIGHTING TECHNOLOGY CENTER

Cottonwood Meadows Survey Apt. #____

New high performance LED lamps and luminaires have recently been installed in your home. This LED technology will provide high quality lighting with a lifespan of 20 years or longer. This technology should save energy and reduce your energy bill. Please answer the following questions based on your experience of the LEDs in your home.

1. **Based on your experience with your new LED lights, rank your top three criteria (1–3 in order of importance) when purchasing lighting products, 1 being the most important consideration, then 2, then 3.**

____ Lifetime (how long it will last)
____ Color Quality (the lights make the color of your belongings/furnishings look good/accurate)
____ Brightness
____ Light Color (warm, cool, etc.)
____ Light Distribution
____ Sustainability/Environmental Impact
____ Product Price
____ Lower Energy Bills

2. **Have the number of waking hours you spend per day at home changed since the installation of the LED lights? (Circle one)**

Home Less Home the Same Home More

3. **How many days a week, typically, are you home between the hours of 9am-5pm? (Circle one)**

0-2 days 3-5 days 6-7days

4. **Do you think the new LED lights have affected the number of hours you now leave your lights on? Do you leave them on less now? About the same? More? (Circle one)**

On Less On the Same On More

5. **Which area of the home do you spend the most time in during waking hours? (Circle one)**

Bathroom Bedroom Closet Kitchen Dining Area Living Area

6. **Has the area where you spend the most time changed since the new LED lighting was installed? (Circle one)**

Yes No

7. **How satisfied are you with the new LED lighting in the following areas of your home?**

	Not Satisfied	Somewhat Satisfied	Neutral	Satisfied	Extremely Satisfied
Bathroom					
Bedroom					
Closet					
Kitchen					
Dining Area					
Living Area					

8. **Which area of your home has seen the largest improvement due to the installation of the new LED lights? (circle one)**

Bathroom Bedroom Closet Kitchen Dining Area Living Area

9. **Since the installation of the new lighting, have you noticed a task with which the new lighting has helped?**

____

10. **If you could further improve the lighting in one area of your home, which area would i be?**

_____ Bathroom
_____ Bedroom
_____ Closet
_____ Kitchen
_____ Dining Area
_____ Living Area

11. **What would you improve about the new lighting?**

____

12. **Which of the following issues bothers you most about the new lighting? Select one.**

___Flicker
___Light Color
___Audible Noise(humming or buzzing)
___Early Failure
___None of the Above

13. **What was your experience with the data monitoring equipment installation conducted as part of this project? (Circle one)**

Unpleasant Mediocre Pleasant

14. **What was your experience with the lighting installation only? (Circle one)**

Unpleasant Mediocre Pleasant

15. Did you find any part of this project intrusive? If yes, what part did you find intrusive? (Circle one)

Yes ______________________________ No

16. Please leave any comments about the installation

____

____

____

____

THANK YOU FOR YOUR INPUT!

Appendix B-5: Pre-Survey Results

Cottonwood Meadows Pre-Retrofit Survey

1. How many waking hours per day do you spend in your home during the SUMMER?

_____ 1 – 5 hours
_____ 6 – 9 hours
_____ 10 – 16 hours
_____ 17+ hours

Apartment	Response
1	6-9 Hours
4	17+ Hours
5	10-16 Hours
15	1-5 Hours
17	10-16 Hours
21	10-16 Hours
22	6-9 Hours
24	1-5 Hours
26	6-9 Hours
27	1-5 Hours
28	10-16 Hours
29	6-9 Hours
30	10-16 Hours
31	10-16 Hours
32	1-5 Hours
33	10-16 Hours
36	6-9 Hours
37	10-16 Hours
38	1-5 Hours
39	1-5 Hours
40	1-5 Hours
42	6-9 Hours
43	1-5 Hours
44	10-16 Hours

2. How many waking hours per day do you spend in your home during the WINTER?

_____ 1 – 5 hours
_____ 6 – 9 hours
_____ 10 – 16 hours
_____ 17+hours

Apartment	Response
1	10-16 Hours
4	17+ Hours
5	10-16 Hours
15	6-9 Hours
17	17+ Hours
21	10-16 Hours
22	10-16 Hours
24	6-9 Hours
26	10-16 Hours
27	10-16 Hours
28	17+ Hours
29	10-16 Hours
30	10-16 Hours
31	10-16 Hours
32	6-9 Hours
33	10-16 Hours
36	10-16 Hours
37	17+ Hours
38	1-5 Hours
39	6-9 Hours
40	1-5 Hours
42	6-9 Hours
43	6-9 Hours
44	10-16 Hours

3. Which area of the home do you spend the most time in during waking hours during the SUMMER? (circle one)

Bathroom Bedroom Closet Kitchen Dining Area Living Area

Apartment	Response
1	Living Area
4	Kitchen; Living Area
5	Living Area
15	Kitchen
17	Living Area
21	Kitchen; Living Area
22	Kitchen
24	Living Area
26	Living Area
27	Closet
28	Bedroom
29	Living Area
30	Bathroom; Bedroom; Kitchen
31	Living Area
32	Bedroom; Kitchen; Living Area
33	Living Area
36	Living Area
37	Dining Area
38	Living Area
39	Kitchen
40	Living Area
42	Living Area
43	Living Area
44	Living Area

4. Which area of the home do you spend the most time in during waking hours during the WINTER? (circle one)

Bathroom Bedroom Closet Kitchen Dining Area Living Area

Apartment	Response
1	Living Area
4	Kitchen; Living Area
5	Living Area
15	Kitchen
17	Living Area
21	Kitchen; Living Area
22	Kitchen
24	Living Area
26	Bedroom
27	Closet
28	Bedroom
29	Living Area
30	Bathroom; Bedroom; Kitchen
31	Living Area
32	Bedroom; Kitchen; Living Area
33	Living Area
36	Living Area
37	Living Area
38	Living Area
39	Living Area
40	Living Area
42	Living Area
43	Living Area
44	Living Area

5. Are there any periods of the year when you are away from home for long periods of time, such as vacations or extended travels etc.? When?

Apartment	Response
1	None
4	No
5	No
15	No
17	No
21	Visiting family/friends – Spring, Summer, Fall
22	None
24	No
26	No
27	Winter (Late December)
28	June
29	No
30	-
31	No
32	No
33	No
36	No
37	N/A
38	October 3-5
39	June (1 Week)
40	1 week
42	No
43	No
44	September (2 Weeks); October (2 Weeks)

6. **Are there any periods of the year when you have extended house guests or more occupants in the residence? When?**

Apartment	Response
1	No
4	No
5	No
15	No
17	No
21	Summer, Spring, Fall - Spring Break
22	None
24	No
26	No
27	Holidays
28	4th, Thanksgiving, Christmas, New Years
29	No
30	-
31	No
32	No
33	No
36	Sometimes Christmas
37	None
38	One per week for one hour
39	Christmas Weekend
40	rare
42	No
43	No
44	None

7. How satisfied are you with the lighting in the rooms of your home?

	Not Satisfied	Somewhat Satisfied	Neutral	Satisfied	Extremely Satisfied
Bathroom					
Bedroom					
Closet					
Kitchen					
Dining Area					
Living Area					

Apt	Bathroom	Bedroom	Closet	Kitchen	Dining	Living
1	Satisfied	Satisfied	Satisfied	Satisfied/Extremely Satisfied	Satisfied	Satisfied
4	Satisfied	Not Satisfied	Satisfied	Satisfied	Neutral	Somewhat Satisfied
5	Somewhat Satisfied	Not Satisfied	Somewhat Satisfied	Somewhat Satisfied	Somewhat Satisfied	Somewhat Satisfied
15	Satisfied	Satisfied	Not Satisfied	Satisfied	Satisfied	Satisfied
17	Not Satisfied	Not Satisfied	Not Satisfied	Not Satisfied	Not Satisfied	Not Satisfied
21	Somewhat Satisfied	Somewhat Satisfied	Satisfied	Extremely Satisfied	Extremely Satisfied	Satisfied
22	Not Satisfied	Not Satisfied	Not Satisfied	Not Satisfied	Not Satisfied	Not Satisfied
24	Somewhat Satisfied	Not Satisfied	Not Satisfied	Somewhat Satisfied	Satisfied	Not Satisfied
26	Not Satisfied	Not Satisfied	Not Satisfied	Not Satisfied	Not Satisfied	Not Satisfied
27	Extremely Satisfied	Not Satisfied	Extremely Satisfied	Satisfied	Not Satisfied	Not Satisfied
28	Somewhat Satisfied	Not Satisfied	Not Satisfied	Somewhat Satisfied	Not Satisfied	Not Satisfied
29	Satisfied	Satisfied	Satisfied	Satisfied	Satisfied	Satisfied
30	Extremely Satisfied	Extremely Satisfied	Extremely Satisfied	Extremely Satisfied	Extremely Satisfied	Extremely Satisfied
31	Somewhat Satisfied	Somewhat Satisfied	Somewhat Satisfied	Somewhat Satisfied	Somewhat Satisfied	Somewhat Satisfied
32	Not Satisfied	Not Satisfied	Not Satisfied	Not Satisfied	Not Satisfied	Not Satisfied
33	Satisfied	Satisfied	Satisfied	Satisfied	Satisfied	Satisfied
36	Somewhat Satisfied	Somewhat Satisfied	Somewhat Satisfied	Somewhat Satisfied	Somewhat Satisfied	Somewhat Satisfied
37	Not Satisfied	Neutral	Satisfied	Neutral	Satisfied	Somewhat Satisfied
38	Satisfied	Somewhat Satisfied	Satisfied	Somewhat Satisfied	Somewhat Satisfied	Satisfied
39	Not Satisfied	Not Satisfied	Not Satisfied	Not Satisfied	Not Satisfied	Not Satisfied
40	Neutral	Somewhat Satisfied	Not Satisfied	Neutral	Neutral	Neutral
42	Not Satisfied	Not Satisfied	Somewhat Satisfied	Satisfied	Somewhat Satisfied	Not Satisfied
43	Somewhat Satisfied	Satisfied	Satisfied	Extremely Satisfied	Satisfied	Satisfied
44	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral

8. Rank the top three criteria (1–3) that are most important to you when purchasing lighting products, 1 being the most important consideration, then 2, then 3.

____ Lifetime (how long it will last)
____ Price
____ Light color ("warm white," "cool white," etc.)
____ Light distribution
____ Brightness

____ Energy efficiency
____ Lower energy bills

____ *Other:*______________________

Apartment	Lifetime	Price	Light Color	Light Distribution	Brightness	Energy Efficiency	Lower Energy Bills
1	3					2	1
4		2				3	1
5		2				3	1
15		3				2	1
17	3			2	1		
21	3					2	1
22	-	-	-	-	-	-	-
24	3	2				1	
26	2				1	3	
27	1				2	3	
28		3				2	1
29	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-
31		3				2	1
32	-	-	-	-	-	-	-
33	1	2			3		
36		3				2	1
37	-	-	-	-	-	-	-
38	-	-	-	-	-	-	-
39		3				2	1
40	1					2	3
42		1			3		2
43	2	1		3			
44	-	-	-	-	-	-	-

9. **If you could improve the lighting in one area of your home, which area would it be?**

_____ Bathroom	_____ Kitchen
_____ Bedroom	_____ Dining Area
_____ Closet	_____ Living Area

Apartment	Response
1	Living Area
4	Living Area
5	Bedroom
15	Kitchen
17	Living Area
21	Bathroom
22	Kitchen
24	Kitchen
26	Bathroom; Bedroom; Kitchen
27	Living Area
28	Bedroom
29	Living Area
30	Bathroom; Living Area
31	Kitchen
32	Bedroom; Living Area
33	Bedroom
36	Bedroom; Living Area
37	Bathroom
38	Dining Area
39	Bathroom
40	Living Area
42	Bathroom
43	Bathroom
44	Bathroom; Kitchen; Living Area

10. What would you improve?

Apartment	Response
1	Brighter
4	More Lighting And Brighter
5	More Lights
15	Brightness
17	More Light
21	Put Light In Bedroom With Fan
22	Some Units Need Bulb
24	No Buzz And Brightness
26	Better Lights Brighter
27	Lighting In Living/Dining Rooms, Ceiling Lights With Fans
28	Lighting Color
29	Better Lighting From Ceiling Light In Living Room
30	Add A Ceiling Fan
31	Brightness
32	Just The Lighting
33	-
36	No, Light In The Bedroom
37	Light Over Sink In Bathroom
38	-
39	Brighter
40	Living Room
42	Brightness
43	Light Won’t Go On If I Forget To Turn On Vent When I Shower, But I Leave Window Open
44	Different Type Of Lighting

11. Name one task you frequently do in your home that requires high-quality lighting:

____

Apartment	Response
1	None
4	Crochet, Reading, Painting
5	Crafts And Reading
15	Reading
17	Reading
21	Reading-Studying
22	Cooking
24	Reading And Sewing
26	Kitchen Bedroom
27	Kitchen Closet
28	Cleaning And Cooking
29	Reading
30	No
31	Reading
32	Reading
33	Writing
36	Reading
37	Shaving
38	Reading Writing
39	Reading
40	Reading And Cleaning
42	Fixing Electrical Things
43	N/A
44	Reading

12. How satisfied are you with the current lighting you have for that task?

_____ Not satisfied
_____ Somewhat satisfied
_____ Neutral
_____ Satisfied
_____ Extremely satisfied

Apartment	Response
1	Satisfied
4	Not Satisfied
5	Not Satisfied
15	Satisfied
17	Not Satisfied
21	Satisfied
22	Not Satisfied
24	Somewhat Satisfied
26	Not Satisfied
27	Somewhat Satisfied
28	Not Satisfied
29	Satisfied
30	Extremely Satisfied
31	Somewhat Satisfied
32	Not Satisfied
33	Neutral
36	Somewhat Satisfied
37	Somewhat Satisfied
38	Satisfied
39	Not Satisfied
40	Somewhat Satisfied
42	Somewhat Satisfied
43	Satisfied
44	Neutral

13. In your experience with lighting, which of the following issues has bothered you most? Select one.

____ Cost (too expensive)
____ Early failure
____ Light color
____ Audible noise (humming or buzzing)
____ Slow start time
____ Flicker

____ *Other:* ___________________________

Apartment	Response
1	Light Color
4	Cost (too expensive)
5	Early Failure
15	Early Failure
17	Cost (too expensive)
21	Cost (too expensive)
22	Early Failure
24	Cost (too expensive)
26	Light Color
27	Cost (too expensive)
28	Light Color
29	Audible Noise (humming or buzzing)
30	Slow Start Time
31	Flicker
32	Flicker
33	Flicker
36	Early Failure
37	Light Color
38	Cost (too expensive)
39	Slow Start Time
40	Flicker
42	Flicker
43	Flicker
44	Flicker

14. What is your gender?

_____ Male
_____ Female

Apartment	Response
1	Female
4	Female
5	Female
15	Female
17	Female
21	Male
22	Male
24	Female
26	Female
27	Female
28	Male
29	Female
30	Female
31	Female
32	Female
33	Female
36	Female
37	Male
38	Female
39	Female
40	Female
42	Male
43	Female
44	Male

15. What is your age?

_____ 35 – 44 years old
_____ 45 – 54 years old
_____ 55 – 64 years old
_____ 65 – 74 years old
_____ 75 – 84 years old
_____ 85 years or older

Apartment	Response
1	75-84 Years Old
4	55-64 Years Old
5	65-74 Years Old
15	55-64 Years Old
17	45-54 Years Old
21	65-74 Years Old
22	65-74 Years Old
24	55-64 Years Old
26	55-64 Years Old
27	55-64 Years Old
28	65-74 Years Old
29	75-84 Years Old
30	55-64 Years Old
31	55-64 Years Old
32	55-64 Years Old
33	75-84 Years Old
36	45-54 Years Old
37	75-84 Years Old
38	55-64 Years Old
39	55-64 Years Old
40	75-84 Years Old
42	35-44 Years Old
43	55-64 Years Old
44	65-74 Years Old

16. Which of the following best describes your current employment status?

_____ Retired
_____ Unemployed
_____ Employed Full Time
_____ Employed Part Time
_____ Self-Employed
_____ Prefer not to answer

Apartment	Response
1	Retired
4	N/A
5	Retired
15	Prefer not to Answer
17	Unemployed
21	Retired
22	Retired
24	Employed Full Time
26	Retired
27	Unemployed
28	Retired
29	Retired
30	N/A
31	Prefer not to Answer
32	Retired
33	Retired
36	Retired
37	Retired
38	Retired
39	Employed Full Time
40	Retired
42	Unemployed
43	Employed Full Time
44	Retired

Appendix B-6: Post Survey Results

Cottonwood Meadows Post-Retrofit Survey

New high performance LED lamps and luminaires have recently been installed in your home. This LED technology will provide high quality lighting with a lifespan of 20 years or longer. This technology should save energy and reduce your energy bill. Please answer the following questions based on your experience of the LEDs in your home.

1. Based on your experience with your new LED lights, rank your top three criteria (1–3 in order of importance) when purchasing lighting products, 1 being the most important consideration, then 2, then 3.

____ Lifetime (how long it will last)
____ Color Quality (the lights make the color of your belongings/furnishings look good/accurate)
____ Brightness
____ Light Color (warm, cool, etc.)
____ Light Distribution
____ Sustainability/Environmental Impact
____ Product Price
____ Lower Energy Bills

Apt	Life-time	Color Quality	Bright-ness	Light Color	Light Distribution	Sustainability/ Environmental Impact	Product Price	Lower Energy Bills
1	-	-	-	-	-	-	-	-
4	2						1	3
5	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-
17			1			3		2
21	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-
26	-	-	-	-	-	-	-	-
27	-	-	-	-	-	-	-	-
28	-	-	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-
30	1						2	3
31	-	-	-	-	-	-	-	-
32	3						1	2
33	3						1	2
36	1						3	2
37	3		1					2
38	-	-	-	-	-	-	-	-
39	2				1			3
40	1						3	2
42	1						2	3
43	1						2	3
44	1						2	3

2. Have the number of waking hours you spend per day at home changed since the installation of the LED lights? (Circle one)

Home Less Home the Same Home More

Apartment	Response
1	-
4	Home the Same
5	-
15	Home Less
17	Home More
21	Home the Same
22	-
24	-
26	-
27	-
28	Home the Same
29	-
30	Home the Same
31	Home the Same
32	Home the Same
33	Home the Same
36	Home the Same
37	Home the Same
38	-
39	Home the Same
40	Home Less
42	Home the Same
43	Home the Same
44	Home the Same

3. How many days a week, typically, are you home between the hours of 9am-5pm? (Circle one)

0-2 days 3-5 days 6-7days

Apartment	Response
1	-
4	3-5 Days
5	-
15	3-5 Days
17	0-2 Days
21	6-7 Days
22	-
24	-
26	-
27	-
28	6-7 Days
29	-
30	6-7 Days
31	6-7 Days
32	6-7 Days
33	6-7 Days
36	6-7 Days
37	6-7 Days
38	-
39	3-5 Days
40	3-5 Days
42	6-7 Days
43	6-7 Days
44	6-7 Days

4. Do you think the new LED lights have affected the number of hours you now leave your lights on? Do you leave them on less now? About the same? More? (Circle one)

On Less On the Same On More

Apartment	Response
1	-
4	On the Same
5	-
15	On the Same
17	On the Same
21	On Less
22	-
24	-
26	-
27	-
28	On the Same
29	-
30	On the Same
31	On the Same
32	On the Same
33	On the Same
36	On the Same
37	On the Same
38	-
39	On the Same
40	On Less
42	On the Same
43	On the Same
44	On the Same

5. Which area of the home do you spend the most time in during waking hours? (Circle one)

Bathroom Bedroom Closet Kitchen Dining Area Living Area

Apartment	Response
1	-
4	Living Area
5	-
15	Kitchen; Dining Area
17	Living Area
21	Living Area
22	-
24	-
26	-
27	-
28	Bedroom
29	-
30	Living Area
31	Living Area
32	Kitchen
33	Living Area
36	Closet
37	Dining Area
38	-
39	Living Area
40	Bathroom; Kitchen
42	Bedroom; Kitchen
43	Living Area
44	Bedroom

6. Has the area where you spend the most time changed since the new LED lighting was installed? (Circle one)

Yes No

Apartment	Response
1	-
4	No
5	Yes
15	No
17	Yes
21	-
22	-
24	-
26	No
27	-
28	No
29	Yes
30	No
31	No
32	No
33	Yes
36	-
37	No
38	No
39	Yes
40	No
42	No
43	-
44	-

7. How satisfied are you with the new LED lighting in the following areas of your home?

	Not Satisfied	Somewhat Satisfied	Neutral	Satisfied	Extremely Satisfied
Bathroom					
Bedroom					
Closet					
Kitchen					
Dining Area					
Living Area					

Apartment	Bathroom	Bedroom	Closet	Kitchen	Dining Area	Living Area
1	-	-	-	-	-	-
4	Extremely Satisfied	Satisfied	Satisfied	Extremely Satisfied	Extremely Satisfied	Satisfied
5	-	-	-	-	-	-
15	Not Satisfied	Not Satisfied	Satisfied	Satisfied	Satisfied	Satisfied
17	Satisfied	Somewhat Satisfied		Satisfied	-	Satisfied
21	Extremely Satisfied	Extremely Satisfied	Extremely Satisfied	Extremely Satisfied	Extremely Satisfied	Extremely Satisfied
22	-	-	-	-	-	-
24	-	-	-	-	-	-
26	-	-	-	-	-	-
27	-	-	-	-	-	-
28	Satisfied	Satisfied	Satisfied	Extremely Satisfied	Satisfied	Satisfied
29	-	-	-	-	-	-
30	Satisfied	Satisfied	Satisfied	Extremely Satisfied	Satisfied	Satisfied
31	Extremely Satisfied	Satisfied	Neutral	Extremely Satisfied	Satisfied	Neutral
32	Satisfied	Satisfied	Satisfied	Extremely Satisfied	Satisfied	Satisfied
33	Satisfied	Satisfied	Satisfied	Extremely Satisfied	Satisfied	Extremely Satisfied
36	Extremely Satisfied	Satisfied	Satisfied	Extremely Satisfied	Extremely Satisfied	Satisfied
37	Extremely Satisfied	Satisfied	Satisfied	Extremely Satisfied	Extremely Satisfied	Extremely Satisfied
38	-	-	-	-	-	-
39	Neutral	Satisfied	Satisfied	Satisfied	Satisfied	Neutral
40	Satisfied	Extremely Satisfied	Satisfied	Extremely Satisfied	Satisfied	Satisfied
42	Satisfied	Satisfied	Satisfied	Extremely Satisfied	Satisfied	Satisfied
43	Satisfied	Satisfied	Satisfied	Extremely Satisfied	Extremely Satisfied	Satisfied
44	Satisfied	Satisfied	Satisfied	Extremely Satisfied	Satisfied	Satisfied

8. Which area of your home has seen the largest improvement due to the installation of the new LED lights? (circle one)

Bathroom Bedroom Closet Kitchen Dining Area Living Area

Apartment	Response
1	-
4	Bathroom; Closet
5	-
15	Kitchen
17	Bathroom
21	Kitchen
22	-
24	-
26	-
27	-
28	Kitchen
29	-
30	Kitchen
31	Kitchen
32	Kitchen
33	Kitchen
36	Kitchen
37	Bathroom
38	-
39	Bathroom
40	Bathroom; Kitchen
42	Bedroom
43	Bathroom; Kitchen
44	Kitchen

9. Since the installation of the new lighting, have you noticed a task with which the new lighting has helped?

Apartment	Response
1	-
4	Reading, Crochet
5	-
15	Reading
17	Bathroom
21	Kitchen
22	-
24	-
26	-
27	-
28	Yes
29	-
30	-
31	Reading
32	Cooking
33	Brighter
36	Cooking In Kitchen
37	Kitchen
38	-
39	Bathroom And Kitchen
40	Cooking
42	Shaving
43	Cooking
44	-

10. If you could further improve the lighting in one area of your home, which area would it be?

_____ Bathroom

_____ Bedroom

_____ Closet

_____ Kitchen

_____ Dining Area

_____ Living Area

Apartment	Response
1	-
4	Bedroom; Living Area
5	-
15	Kitchen
17	Bedroom; Closet; Living Area
21	Bedroom
22	-
24	-
26	-
27	-
28	Closet; Kitchen; Living Area
29	-
30	Bedroom
31	-
32	Bedroom
33	Bedroom
36	Bedroom
37	Bedroom
38	-
39	Closet
40	Bedroom
42	Bedroom
43	Bedroom
44	Bedroom

11. What would you improve about the new lighting?

Apartment	Response
1	-
4	More of Them
5	-
15	Nothing
17	Brighter
21	Nothing
22	-
24	-
26	-
27	-
28	-
29	-
30	Nothing
31	-
32	Nothing
33	Nothing
36	Nothing
37	Nothing
38	-
39	Lamps not as Bright
40	Nothing
42	Nothing
43	Nothing
44	Nothing

12. Which of the following issues bothers you most about the new lighting? Select one.

___Flicker

___Audible Noise(humming or buzzing)

___Light Color

___Early Failure

___None of the Above

Apartment	Response
1	-
4	None of the Above
5	-
15	None of the Above
17	None of the Above
21	None of the Above
22	-
24	-
26	-
27	-
28	None of the Above
29	-
30	None of the Above
31	Audible Noise (humming or buzzing)
32	None of the Above
33	None of the Above
36	None of the Above
37	None of the Above
38	-
39	None of the Above
40	None of the Above
42	None of the Above
43	None of the Above
44	None of the Above

13. What was your experience with the data monitoring equipment installation conducted as part of this project? (Circle one)

Unpleasant Mediocre Pleasant

Apartment	Response
1	-
4	Mediocre
5	-
15	Mediocre
17	Unpleasant
21	Pleasant
22	-
24	-
26	-
27	-
28	Mediocre
29	-
30	Pleasant
31	Mediocre
32	Pleasant
33	Pleasant
36	Pleasant
37	Pleasant
38	-
39	Mediocre
40	Pleasant
42	Pleasant
43	Pleasant
44	Pleasant

14. What was your experience with the lighting installation only? (Circle one)

Unpleasant Mediocre Pleasant

Apartment	Response
1	-
4	Pleasant
5	-
15	Unpleasant
17	Mediocre
21	Pleasant
22	-
24	-
26	-
27	-
28	Pleasant
29	-
30	Pleasant
31	Mediocre
32	Pleasant
33	Pleasant
36	Pleasant
37	Pleasant
38	-
39	Pleasant
40	Pleasant
42	Pleasant
43	Pleasant
44	Pleasant

15. Did you find any part of this project intrusive? If yes, what part did you find intrusive? (Circle one)

Yes ________________________________ No

Apartment	Response
1	-
4	Yes
5	-
15	No
17	Yes
21	No
22	-
24	-
26	-
27	-
28	No
29	-
30	No
31	No
32	No
33	No
36	No
37	No
38	-
39	No
40	No
42	No
43	No
44	No

16. Please leave any comments about the installation

Apartment	Response
1	-
4	-
5	-
15	-
17	-
21	-
22	-
24	-
26	-
27	-
28	-
29	-
30	-
31	-
32	-
33	-
36	-
37	-
38	-
39	-
40	-
42	-
43	-
44	-

Appendix B-7: Measured Energy Use

Appendix F: Metered Energy Logging

Using installed lighting loads and lighting utilization data for the retrofitted apartments, calculated energy savings for the installation was 76.6 percent. Post-retrofit data on lighting-time-of-use, indicated that occupants substantially increased their lighting use during the post-retrofit period. Use increased by an average of 11 percent, resulting in only 12 percent savings between the pre and post-retrofit systems when considering collected data only. Such a comparison does not accurately represent the savings associated with the demonstrated technology. As such, savings, assuming baseline energy use and post-retrofit hours-of-use is most meaningful to understand the technology's energy impacts.

Results also indicate the need for further standardization of logging and analysis processes for residential applications. Residential electrical circuits in residences do not typically separate lighting and plug loads, making the use of panel logging equipment less straight-forward than in commercial applications. Additional error is introduced into the analysis by adding plug-load monitoring equipment reliant on network connections and limited on-board memory.

The following section provides the data and data reduction steps performed on collected data per the *Measurement and Verification Plan*.

Lighting Energy Use

To benchmark the energy performance of the pre-retrofit lighting system, energy use data was collected per the project's *Measurement and Verification Plan*. Monitoring systems that experienced errors during pre- and/or post-retrofit data collection periods were not included in the analysis (see Table 12 for error type).

Apartments were monitored from January 5, 2015 to January 18, 2015 (14 days) to establish a benchmark for lighting energy use. Table 1 provides benchmark monitoring details and lighting energy use per apartment.

Table 1. Pre-Retrofit Energy Use Monitoring – Summary

Apartment	Average Daily Energy Use (kWh)	Calculated Annual Energy Use (kWh)
1	1.14	416.1
5	1.53	558.5
44	1.30	474.5
4	0.39	142.4
17	0.99	361.4
21	0.74	270.1
28	1.56	569.4
30	0.81	295.9
31	0.72	263.3
32	0.61	222.2

33	1.84	671.5
36	2.22	809.8
38	0.14	51.1
42	1.78	649.7
43	0.5	182.5
Average	**1.08**	**395.9**

To quantify the energy savings of the post-retrofit lighting system compared to the benchmark system, lighting energy use data was collected per the *Measurement and Verification Plan* section of this report. The 24 participating apartments in this study were monitored. Table 2 provides monitoring period details per apartment. 63% of the apartments included in this study provided data from both panel and receptacle logging equipment with significant length monitoring periods to be included in the lighting use energy analysis. Significant length was defined as two weeks for the purposes of this study.

For apartments that were "dropped from the analysis due to limited monitoring period for the post-retrofit", this was due to the receptacle logging manufacturer experiencing a lapse in cellular network coverage. This created varied monitoring periods per apartment, with some periods being too short to include in the analysis.

Table 1. Post-Retrofit Monitoring Period Details

Apt.	Lighting Energy Use Monitoring - Analysis Notes
1	Keep in analysis
5	Keep in analysis
22	*Dropped from analysis - apartment was vacant during pre-retrofit monitoring period*
24	*Dropped from analysis - limited monitoring period for post-retrofit*
26	*Dropped from analysis - limited monitoring period for post-retrofit*
29	*Dropped from analysis - limited monitoring period for post-retrofit*
44	Keep in analysis
4	Keep in analysis
15	*Dropped from analysis - limited monitoring period for post-retrofit*
17	Keep in analysis
21	Keep in analysis
27	*Dropped from analysis - no data available*
28	Keep in analysis
30	Keep in analysis

31	Keep in analysis
32	Keep in analysis
33	Keep in analysis
36	Keep in analysis
37	*Dropped from analysis - unable to monitor 'breathing machine' receptacle load*
38	Keep in analysis
39	*Dropped from analysis - apartment was vacant during pre- and post-retrofit monitoring periods*
40	*Dropped from analysis - limited monitoring period for post-retrofit*
42	Keep in analysis
43	Keep in analysis

Lighting energy-use results are provided in Table 3 for apartments identified in Table 2 as appropriate for inclusion. The calculated annual energy use assumes average daily energy use derived from the monitored lighting energy use is applicable to 365 days per year.

Table 2. Post-Retrofit Energy Use Monitoring - Summary

Apt.	Number of Days Monitored	Average Daily Energy Use (kWh)	Calculated Annual Energy Use (kWh)
4	25	0.40	145.6
17	20	0.82	300.2
21	20	0.51	185.4
28	13	0.64	235.4
30	21	1.06	388.1
31	13	0.80	291.5
32	20	0.59	215.8
33	24	1.53	557.1
36	21	2.77	1,010.1
38	25	0.11	40.5
42	20	1.38	504.7
43	24	0.21	75.4
AVG	**-**	**0.90**	**329.2**

Based on the calculated annual lighting energy use in Table 14, savings vary from -31.2% to 58.7% with the average monitored apartment saving 12.0% lighting energy use over the pre-retrofit lighting system defined in the *Benchmarking* section of this report. Variation in savings due to occupant hospitalization and vacations can be correlated using occupant notes in Table 4 and survey responses contained in Appendix D.

Table 4. Lighting Energy Use Savings – Retrofitted Apartments

Apt.	Pre-Retrofit Annual Energy Use (kWh)	Post-Retrofit Annual Energy Use (kWh)	Annual Energy Use Savings (kWh)	Energy Savings (%)
4	142.4	145.6	-3.2	-2.3%
17	361.4	300.2	61.2	16.9%
21	270.1	185.4	84.7	31.4%
28	569.4	235.4	334	58.7%
30	295.9	388.1	-92.2	-31.2%
31	263.3	291.5	-28.2	-10.7%
32	222.2	215.8	6.4	2.9%
33	671.5	557.1	114.4	17.0%
36	809.8	1,010.1	-200.3	-24.7%
38	51.1	40.5	10.6	20.7%
42	649.7	504.7	145	22.3%
43	182.5	75.4	107.1	58.7%
AVG	**374.1**	**329.2**	**44.9**	**12.0%**